January, 1941
Volume 39, No. 1

Metal Progress

table of contents

Published monthly and copyrighted, 1941, by American Society for Metals, 7301 Euclid Ave., Cleveland, Ohio. Subscriptions $5 a year in U. S. and Canada (foreign, $7.50); current copies $1; special reference issues $2. Entered as second-class matter, Feb. 7, 1921, at the post office at Cleveland, under the Act of March 3, 1879. The American Society for Metals is not responsible for statements or opinions printed in this publication.

Cover is an impressionistic artist's idea of hardness testing. Recognize the Brinell, Vickers and Knoop indentations?

Owned and Published by
AMERICAN SOCIETY for METALS

Airplane View of the Principal Plant of Inland Steel Company

This aerial photograph, taken at an altitude of 1,000 feet, shows the Indiana Harbor Works, on the south shore of Lake Michigan. The No. 1 unit, and the administration building, are in the foreground. Across the tracks is

By A. P. Terrile
and P. R. Brucker
Metallurgical Laboratory
Pittsburgh Crucible Steel Co.
Midland, Pa.

The end-quench test for evaluating heats of steel

EVER SINCE 1922, when McQuaid and Ehn published their classic paper on the "Effect of Quality of Steel in Case Carburizing Results", metallurgists have been engaged in extensive research to improve their methods of testing. The purpose was to anticipate the physical characteristics of steels, particularly with reference to applications in service.

The fields of study receiving the most attention recently are grain size and hardenability. Many methods of grain size determinations and methods of hardenability measurements have been developed. With proper interpretation practically all have considerable merit. The almost limitless applications and uses have made the attainment of a single standardized test for either grain size or hardenability of the S.A.E. steels seem only a remote possibility.

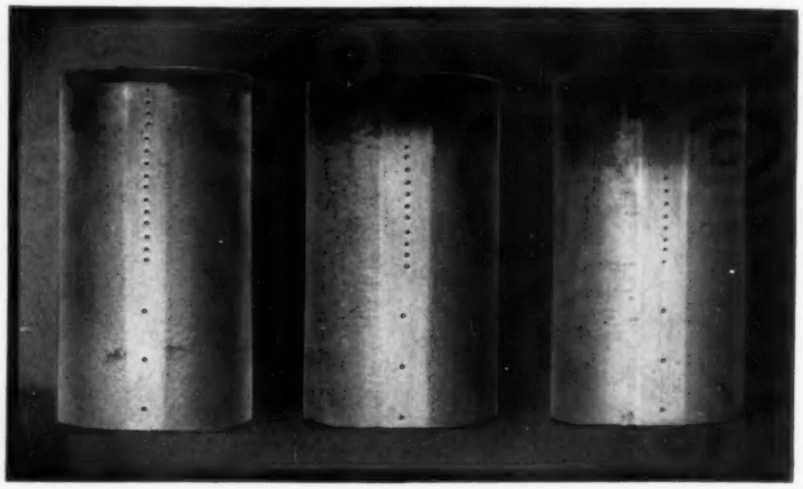
Among the most practical methods of hardenability testing is the end-quench test devised by W. E. Jominy and A. L. Boegehold of General Motors' Research Laboratories. Because of its simplicity, accuracy and reproducibility, their method should come the closest to a standardized measuring stick for evaluating the hardenability of different grades and heats of steel. The recent revision of the design of the specimen to measure more accurately the hardenability of the low carbon grades and shallow hardening steels is an additional enhancement of this possibility. Detailed information on these tests may be secured from original articles in the ⊕ Carburizing Symposium, Hardenability Symposium, and *Transactions* for December 1939. Summaries have been published in Metal Progress by Robert S. Archer (January to March 1939) and in November 1940 by Mr. Jominy himself.

The practical use of the end-quench test is shown by two outstanding features. The first is the extremely rapid quenching of the base end of the specimen by continuous contact with an impinging stream of water; gradually slower rates of cooling occur from this point to the upper, unquenched end of the specimen. The second feature is the speed and facility of obtaining the hardness values. No delay occurs because of cutting and grinding sections with attendant danger of tempering, as is the case with the fully quenched cylindrical specimens which require a hardness survey of a transverse section.

The value of any test is to correlate its results to the use of the material in service. The end-quench test ideally serves this purpose for steel, because the cooling rates as measured along the specimen may be correlated by comparative measurements of cooling rates at any selected location on heat treated parts. Jominy has explained how this is done in his paper in Metal Progress two months ago.

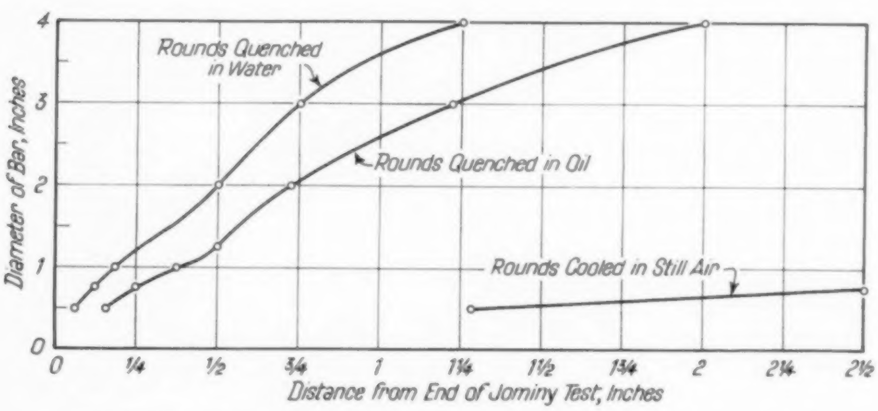
It is also true that the metallurgical laboratories of the various steel manufacturers should have a practical and useful tool for evaluating grades and heats of steel in terms of hardenability. Such an evaluation, with the cooperation of the consumer, will result in a more intelligent application of steel with the proper hardening characteristics for the intended serv-

Hardenability Line as Developed by Etching End-Quench Test Pieces in 20% Nitric Acid in Alcohol. "Hardenability Numbers" are 1, 5 and 8 respectively



ice. With this in view, the metallurgical laboratory of the Pittsburgh Crucible Steel Co. has developed, by means of the end-quench test, a practical method for steel evaluation at the source.

We have found that all the water and oil hardening S.A.E. steels may be evaluated by this method, if they have sufficient hardenability to harden to Rockwell C-50 at a minimum distance of 2/16 in. from the quenched end. C-50 hardness was selected arbitrarily; its location on the end-quench specimen in many steels, particularly carbon steels, is sufficiently sharp to be revealed by suitable etching. The accompanying halftone illustrates this hardenability line as revealed by etching in a 20% solution of nitric acid and alcohol. The value of Rockwell C-50, when referring to center hardnesses of rounds (as determined by comparison with the corresponding distance measured on the JOMINY specimen) is intended to imply "critical hardening size"



Meaning of These Curves: Steel at the surface of a Jominy (end-quench) test piece and ¾ in. from its end — for example — will cool through the critical range at the same rate as the center of a 2-in. bar quenched in oil, or a 3-in. bar quenched in water

as set forth by Messrs. Grossmann, Asimow and Urban in the 1939 Hardenability Symposium, ⊕.

The hardness impressions shown on the sides of the specimens are taken at sixteenths of an inch increments a distance of one inch from the quenched end of the specimen. With the exception of very deep hardening steels the C-50 value always occurs within this distance. When steels show greater hardnesses one inch from the end, the Rockwell impressions are continued at sixteenths to a distance ⅛ in. beyond the point where C-50 is found. At distances further than one inch the change in hardness is usually so gradual that the impressions may be more widely spaced.

Samples from a heat of steel which harden 2/16 in. from the quenched end to C-50 are given a hardenability number of 2. Another heat that would harden to Rockwell C-50 at a distance of 8/16 in. would by the same token be termed a No. 8 hardenability steel.

In order to correlate these hardenabilities with centers of sections of increasing diameter, curves were re-plotted from cooling data shown in JOMINY's paper in the ⊕ Hardenability Symposium. These curves, reproduced at the left, show the cooling rates at various distances along the end-quench specimen versus the center cooling rates of rounds of various cross sections when quenched by immersion. For convenience our "hardenability numbers for heat evaluation" and the corresponding diameters of rounds are shown in the first table on the next page.

We have made many experiments to verify these figures and find that the actual center hardnesses of ¾ to 3-in. rounds, when quenched either in water or oil, have checked invariably with hardnesses found at the distances along

the end-quench specimen called for on the before-mentioned chart.

Some comparative results are shown in the second table. In these tests the oil used was Houghton's No. 2 maintained between 90 and 110° F. Scale and decarburization were machined from the bars before treatment, and the rounds quenched vertically and agitated mildly by hand.

Correlation of Hardenability Number With Critical Hardening Size

Hardenability Number	Diameter of Round in Inches Having Equivalent Center Cooling Rate		
	In Water	In Oil	In Air
1	½	..	..
2	¾	..	..
3	1	⅝	..
4	1¼	¾	..
5	1⅜	⅞	..
6	1½	1	..
7	1¾	1⅛	..
8	2	1¼	..
9	2¼	1½	..
10	2½	1¾	..
11	2¾	1⅞	..
12	3	2	..
13	3⅛	2¼	..
14	3⅜	2⅜	..
15	3½	2½	..
16	3⅝	2⅝	..
20	4	3	½
24	..	3½	..
28	..	3¾	..
32	..	4	..
40	..	..	¾

In routine appraisal of mill heats, samples for hardenability testing are selected generally from bloom or billet sections. The test pieces are forged to 1⅛-in. rounds. Prior to machining they are given preliminary heat treatments corresponding to those they will get in the hands of the user. Quenching temperatures and time cycles are also the same as employed for the finished parts.

In order to correlate the grain size of the steel *at the normal quenching temperature* with the hardenability results, "oxidation" grain size tests are conducted along with the end-quench tests. Oxidation specimens are prepared from disks from the same sections of steel as the Jominy specimens; these are charged together into the furnace and quenched into a 10% brine solution. The specimens are then polished and etched for grain size examination as described by Herasymenko in Metal Progress, Sept., 1936. A more complete determination of the grain size characteristics of a heat may thus be obtained. It is quite generally recognized that the temperature of 1700° F. required by the McQuaid-Ehn carburizing test is usually well above the temperatures employed for normalizing or quenching the water and oil hardening steels. In many instances steels which have coarsened at 1700° F. are still uniformly fine grained at correct quenching temperatures.

Control of Steel for Slider Gear

The application of a 0.50% carbon steel for a transmission gear (second and third speed slider gear) is an example requiring close control of the hardenability number, heat by heat. The system of testing outlined above showed best results were secured from heats with No. 4 and No. 5 end-quench hardenability. The sensitivity of this grade of steel in relation to equivalent critical hardening sizes, differences in grain size, and content of carbon, manganese and chromium, is shown by end-quench tests in the tabulation on the next page. The analyses are those of the respective test specimens rather than heat analyses or check analyses.

Verification of Correlation for Various Steels and Sizes

S.A.E. No.	Diameter of Round	Oil Quenched From (° F.)	Rockwell Hardness	
			Center of Round	Equivalent Distance on Jominy Specimen
1035	1 in.	1550	C-28	C-30
1065	1	1525	36	36
0.40 C-Mo	1	1550	49	51
0.40 C-Mo	1½	1550	35	36
T-1340	1	1550	49	48
T-1345	¾	1550	56	56
T-1345	1	1550	54	54
3135	1	1550	47	46
4140	1	1550	55	54
5135	¾	1550	50	50
5135	1	1550	44	42
6150	1	1550	58	59
6150	2	1550	48	49
6150	3	1550	38	40

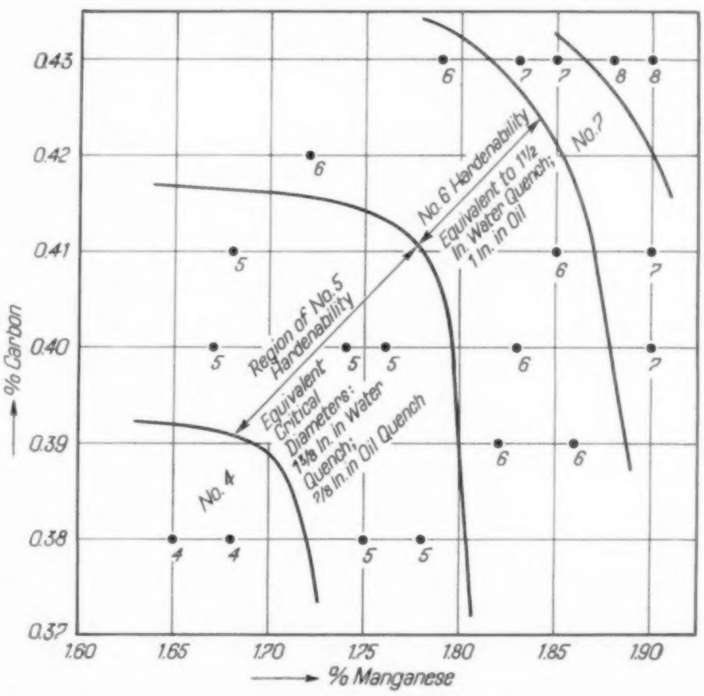
By using the end-quench test for evaluation, satisfactory mill heats are consistently supplied, even though some steels may vary in grain

Variation, Heat to Heat, in 1050 Steel for Slider Gears

Analysis				Grain Size No.		End-Quench Harden-ability Number	Equivalent Critical Diameter	
C	Mn	Si	Cr	McQuaid-Ehn (1700° F.)	Oxidation (1550° F.)		Water Quench	Oil Quench
0.48	0.65	0.21	0.07	3	7	2	5/8 in.	..
0.48	0.67	0.19	0.09	3	7	2	5/8	..
0.51	0.88	0.22	0.08	3	7	3	1	1/2 in.
0.50	0.80	0.24	0.25	7	8	4	1 1/4	3/4
0.52	0.82	0.23	0.24	3	7	5	1 3/8	7/8
0.53	0.84	0.22	0.23	3	7	5	1 3/8	7/8

coarsening temperature and show slight differences in chemistry. The outstanding essential in promoting adequate hardenability for this part was the penetration effect induced by the proper manganese content.

As another example of the utility of the methods described above, take the close control of melting practice giving heats uniformly fine-grained at 1700° F.; the hardenability of the S.A.E. 1340 steel may be maintained to close limits throughout the normal range of chemistry. Plots on the adjoining diagram illustrate a series of heat evaluations on this grade of steel, and show the effect of slightly increased carbon content and the effect of higher percentages of manganese in producing deeper hardening and larger critical hardening sizes. Applications of heats shown by evaluation to be from No. 4 to No. 5 end-quench hardenability have been consistently satisfactory for transmission spline shafts and first and reverse slider gears. If a steel with excessively deep hardening characteristics is used for spline shafts, high distortion and consequent breakage during the straightening operation will result.



Hardenability Numbers of 20 Heats of S.A.E. 1340 Steel, Indicating Variation With Normal Variations in Carbon and Manganese Contents

Heats of S.A.E. 1340 used for steering knuckles should have a high end-quench hardenability, that is to say, No. 6 through No. 8 for excellent heat treating results.

The table on page 41 lists the heat evaluations and equivalent critical hardening sizes of various S.A.E. steels. The deeper hardening character of one of the 3135 steels was induced by its appreciably higher percentage of alloy, especially manganese; it had the same hardenability as the fine-grained 3140. The chromium-molybdenum S.A.E. 4135 steel, fine grained, showed the same hardenability as the straight chromium S.A.E. 5135 of the coarse grain type. The 6150 and 3150 steels were both very deep hardening.

Although hardening characteristics may be anticipated to a reasonable degree in steels by close control of analysis, grain size and melting practice, nevertheless the end-quench test and our system of evaluation of heats affords a ready and convenient method of actually knowing the true situation. This is accomplished to a degree of practical accuracy comparable to other well known methods of testing the physical characteristics of steels. In fact, the reproducibility is closer than sometimes attained by laboratory quenching of cylindrical sections. This is appar-

Hardenability Evaluation of Representative Heats of S.A.E. Steels

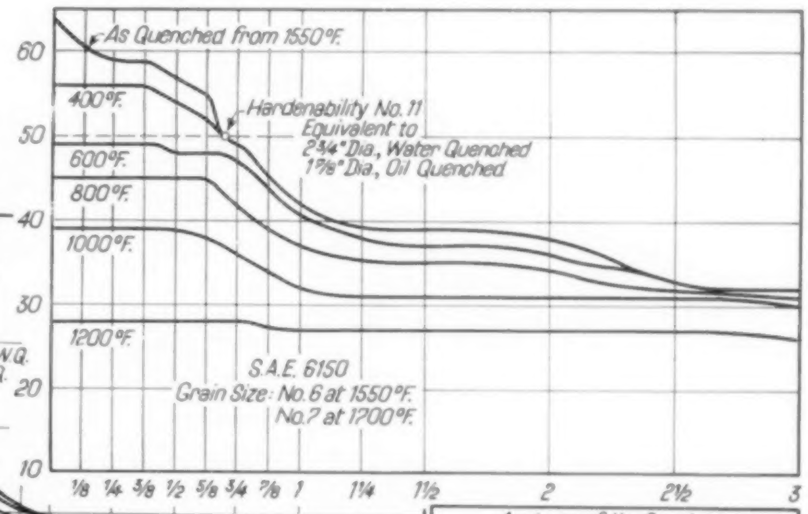
S.A.E. No.	Chemical Analysis					Grain Size No.		End-Quench Hardenability Number	Equivalent Critical Diameter	
	C	Mn	Ni	Cr	Mo	McQuaid-Ehn (1700° F.)	Oxidation at —— °F.		Water Quench	Oil Quench
3135	0.36	0.63	1.18	0.60	....	3	6 at 1550	4	1¼ in.	¾ in.
3135	0.36	0.78	1.35	0.69	....	3	7 1550	6	1½	1
3140	0.42	0.75	1.41	0.72	....	7	8 1550	6	1½	1
5135	0.35	0.75	....	1.08	....	3	7 1575	4	1¼	¾
4135	0.35	0.70	....	1.06	0.21	7	8 1575	4	1¼	¾
4140	0.41	0.65	....	0.95	0.19	6	7 1550	6	1½	1
4140	0.39	0.77	....	1.02	0.21	6	7 1550	7	1¾	1⅛
2330	0.32	0.68	3.44	....	....	7	8 1550	4	1¼	¾
C-Mo	0.62	0.76	....	....	0.20	8	8 1525	5	1⅜	⅞
6150	0.52	0.75	....	1.00	0.19 V	7	8 1550	11	2¾	1⅞
3150	0.48	0.74	1.38	0.72	....	7	8 1550	10	2½	1¾

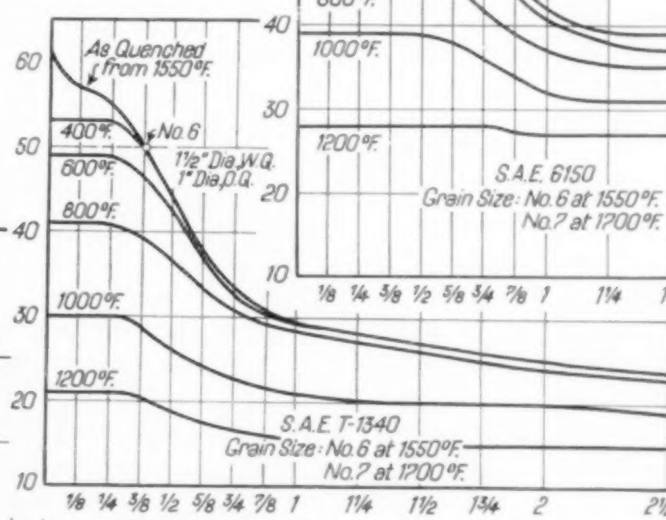
ent, particularly, in the oil quenching of grades and sizes of such hardenability that the efficiency of the quench is materially influenced by scale, decarburization, oil temperature, viscosity, and circulation.

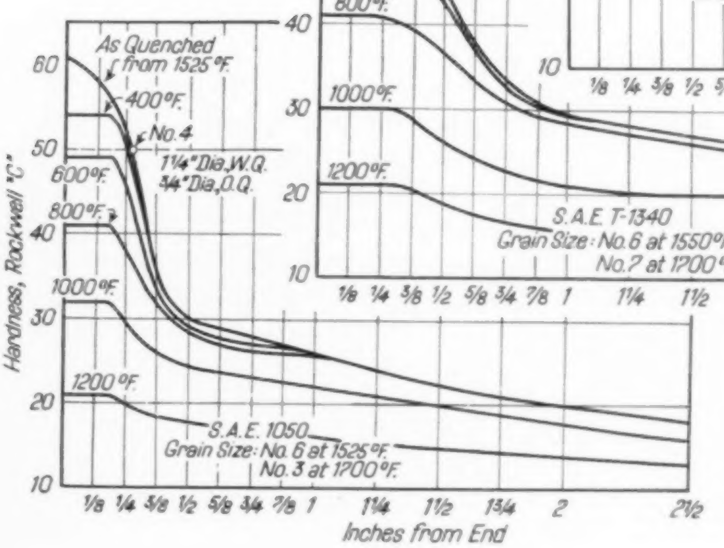
Tempering of Test Pieces

Tests are now being run to determine the changes in hardness along end-quench specimens of various S.A.E. steels after tempering. The results may be interpreted in relation to critical hardening sizes in the same manner as the as-quenched Jominy samples. Preliminary results obtained on three grades of S.A.E. steels of hardenability No. 4, 6 and 11 respectively are shown in the graphs assembled at the bottom of this page. Analyses, grain size, and quenching temperatures of the specimens prior to tempering are shown alongside the curves.

Re-Survey of Hardness Along End-Quenched Specimen After Tempering to the Various Temperatures Shown



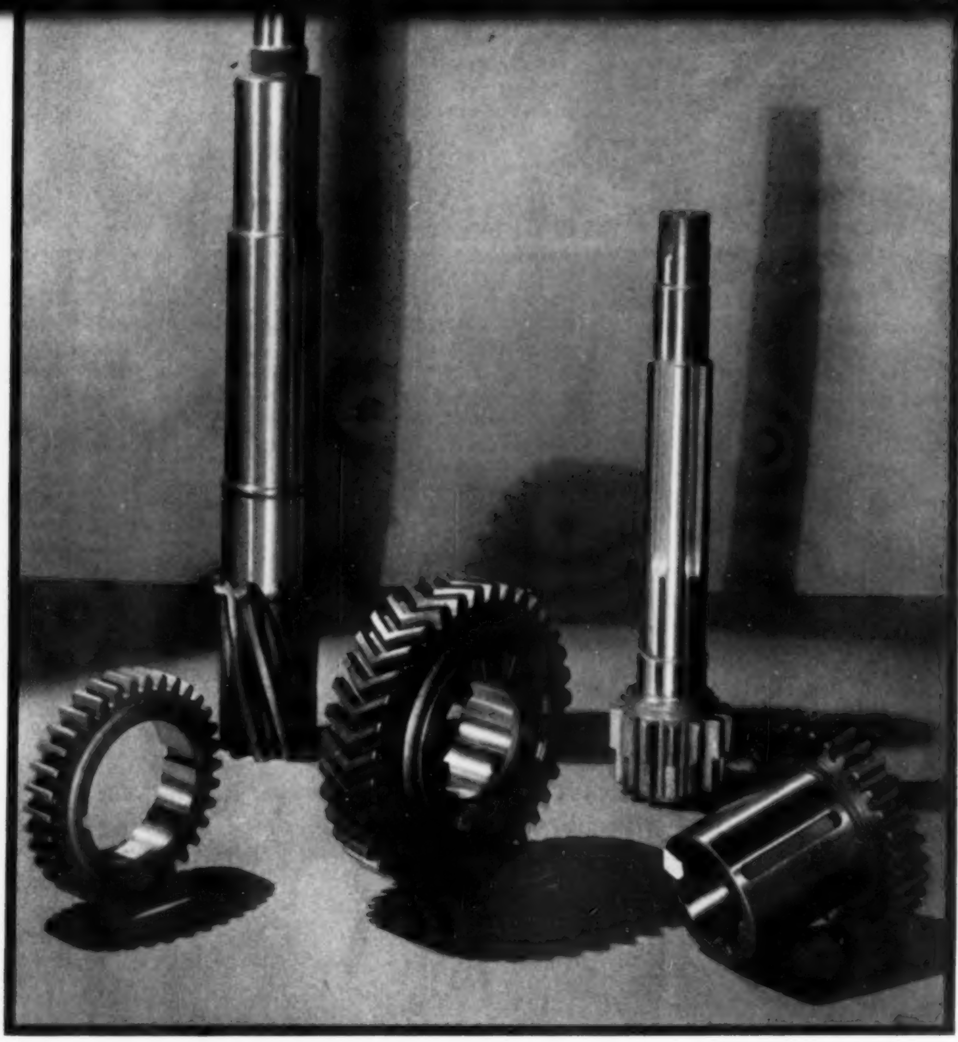




Analyses of the Specimens

	6150	T-1340	1050
C	0.52	0.41	0.50
Mn	0.63	1.89	0.87
P	0.017	0.016	0.022
S	0.029	0.028	0.030
Si	0.20	0.28	0.25
Cr	1.00		
V	0.18		

The drop in hardness of these steels after tempering at various temperatures, at locations on the Jominy specimens equivalent to their respective critical hardening diameters as-quenched either in



water or oil, is illustrated in the small table on this page. The figures were taken from the final curves by drawing a vertical ordinate through the intersection of the as-quenched curve with the C-50 horizontal, and reading the hardnesses where this vertical ordinate intersects the hardness curves after tempering.

The table shows, for example, that the center hardness of a 1⅞-in. oil-quenched round of the 6150 steel as tempered at 1200° F. will have dropped from C-50 to C-28. Slight difference in tempered hardnesses of the steels at their surface is shown in the range from 400 to 600° F. The higher drawing temperatures brought out the considerably greater resistance of the S.A.E. 6150 steel to softening.

The essential value of tempering the end-quench specimens is to determine the softening of the center hardness of the bars of equivalent critical hardening diameters. In this manner, practically the same information may be obtained more readily than by hardening cylinders of critical hardening size, tempering, bisecting them, and determining their center hardness.

The usual procedure for end-quench testing involves a complete graph of the hardness readings. By using the described method of arbitrarily selecting a hardness value in relation to a critical hardening line, the test may be readily interpreted in terms of mass. One practical advantage of this is that it gives us a means of determining critical hardening size in the oil or water hardening S.A.E. steels without the involved procedure of numerous cylindrical specimens of various diameters.

The selection of a hardness value on the Jominy specimen to denote equivalent center hardness may be changed in accordance with any figure desired. For example, if the center hardness of C-45 would be satisfactory for a steel before tempering, then the distance along the Jominy specimen giving this hardness may be selected, rather than the distance to a hardness of C-50, as used herein.

Hardenability is one of the most interesting and important subjects in the metallurgical field and it is hoped that this paper will stimulate further development of methods to interpret hardenability test results with respect to the applications of the steel in final service.

Hardness of End-Quench Specimens, C-50 as Quenched, After Drawing

Drawn at	6150	T-1340	1050
400° F.	C-50	C-50	C-49
600° F.	48	47	45
800° F.	43	39	38
1000° F.	37	29	29
1200° F.	28	21	20

By J. B. Austin
Kearny, N. J.

Getting the most out of modern refractories

THERE IS NO ONE in this country who can read or hear who is not acquainted with the efforts being made to speed up the defense program, and there must be few readers of METAL PROGRESS who have not felt the pressure of this drive in one form or another. Many who are faced with demands for increased production from existing facilities are pushing their equipment to the limit — or beyond. This is particularly true of furnaces of all kinds and it is almost certain that the refractories in many installations are being called upon for "service" which really amounts to abuse.

Although the refractories themselves cannot protest audibly, furnace operators, who are sensitive to the behavior of refractories, can and do so universally — or at least so the brick makers seem to believe. At any rate, there is no question but that there is arising out of the increased metallurgical activity a whole set of problems — many of which are obviously not new but merely aggravated by present conditions — which can best be solved by cooperation between the producer of refractories and the consumer. In the light of this situation, two recent technical meetings devoted to refractory problems have a special interest.

The first was the annual fall meeting of the Refractories Division of the American Ceramic Society, a meeting traditionally devoted to consumer problems. The main subject, "Blast Furnace Refractories", attracted a good number of blast furnace men as well as manufacturers of refractories.

It has long been recognized that one of the chief causes of disintegration of blast furnace brick is the deposition of carbon through the decomposition of carbon monoxide on particles of iron oxide in the brick. Armed with this knowledge the brick makers have made considerable progress toward the removal of this difficulty, but there is still some question as to the most desirable remedy. H. M. KRANER of the Bethlehem Steel Co. led off with an outstanding contribution to this problem. After a careful study of a number of blast furnace linings at the end of their campaign — a study which included chemical and petrographic analyses of samples taken from many different locations within the furnace — he has come to some interesting and apparently well-supported conclusions.

He was unable to find any correlation between the amount of iron in a brick and its susceptibility to disintegration in the neighborhood of 950° F., the temperature at which carbon deposition is most troublesome. Mr. KRANER further believes that merely changing the form of the oxide, as by converting Fe_2O_3 to Fe_3O_4, is not sufficient but that the iron must be converted to a silicate or some other complex compound. In discussion, Dr. UNGER said that in some tests made many years ago, he, too, had failed to find a correlation between iron oxide content and susceptibility to disintegration, but that he believed the amount of acid-soluble iron could be used a criterion.

Another, and almost equally serious, cause of failure, which has not been so widely recognized, is attack by alkali. Mr. KRANER has demonstrated the presence of significant amounts

of nephelite ($Na_2O \cdot Al_2O_3 \cdot 2SiO_2$) in the disintegrated zone and the mode of occurrence indicates that the alkali is not merely absorbed but unites with the original material of the brick in a true fluxing action. Although the demonstration of this fact is an advance in our knowledge, the best antidote for disintegration of blast furnace linings is not yet apparent.

Another factor commonly credited as a cause of failure is slag attack. Mr. KRANER believes that this term has been used much too loosely, that true slag attack occurs only in the bosh of the furnace, and that it is but a secondary influence in the destruction of a lining. He also thinks that the effect of abrasion is not nearly so serious as is commonly supposed since most of the wear is taken by the scab which protects the underlying refractory. The bosh of the furnace and the hearth show heavily vitrified zones and contain anorthite ($CaO \cdot Al_2O_3 \cdot 2SiO_2$) whose presence indicates that in this part of the furnace the chief fluxing agent is lime.

The next speaker, JAMES WEST of Pittsburgh, gave some "Reminiscences on Brick Used for Blast Furnaces and Hot Blast Stoves" which included some very human and open-minded remarks on the cooperation between blast furnace operators and the manufacturers of refractories. He traced the slow recognition of the benefits of such cooperation from the mutual antagonism of 40 years ago to the present more enlightened attitude. That is not to say that present relations resemble a love feast, but the attitude on the whole is more sane and scientific.

Is Bricklaying a Lost Art?

The third paper, by A. M. MORTON of the Pittsburgh Steel Co., dealt with "Expansion and Contraction of Refractories in Blast Furnaces". He is a strong believer in, and made a very effective case for, tight bricklaying and the use of virtually monolithic brickwork. He does not favor the practice of leaving a 3-in. space between the lining and the shell to be filled up later with crushed material to take up the expansion. He has never seen a jacket fail because of expansion, and states that the attempt to leave such a space results in unsymmetrical and inferior brickwork. In his opinion it is much better to use insulating blocks which can be laid right up to the shell and which are soft enough to crush under excessive expansion. Cracked shells are chiefly fatigue failures, a view seconded in discussion by L. A. SMITH.

"Bricklaying is very nearly a lost art," was a statement by MORTON which aroused much discussion after the meeting. There are three general schools of thought: (1) Those who disagreed; (2) those who agreed and blamed the situation on the virtual disappearance of the apprentice system; (3) those who agreed but felt that the trouble was largely due to improper application of time studies and the setting up of a bogey for the job. (If a bricklayer gets a bonus for setting more bricks than the standard rate calls for, there is a great temptation to do sloppy work, since the bricks are soon covered up and the quality of the work cannot easily be checked.) There is probably some merit in each of these views, if one can judge by the distribution of adherents.

This meeting of blast furnace men closed with a paper by CHARLES HART of the Delaware River Steel Corp. on the "Refractory Requirements of the Electric Smelting of Iron Ores". His discussion was based upon experience in Norway and Sweden where two successful smelting processes have been developed. As a matter of fact the refractory problems in these processes have not been serious and could readily be solved with materials available in this country. One thing which must be guarded against in electric smelting is a lining which becomes a fair electrical conductor at the high temperatures involved.

The Swedish process uses a shaft-type furnace, usually producing about 60 tons a day, with charcoal or coke as the reducing agent. The Norwegian development is a pit-type furnace, producing about 100 tons a day, which operates on inferior grades of fuel for its source of carbon. Because of this adaptability to low-grade fuel and because of the relative ease with which a number of different grades of iron can be produced it is likely that the Norwegian process will eventually displace the Swedish furnace. Sintered magnetite is favored as an ore. The use of electric power as a source of heat enables these furnaces to approach the theoretical amount of carbon required for reduction of the iron oxide, and they have used as little as 800 lb. of carbon per ton of iron.

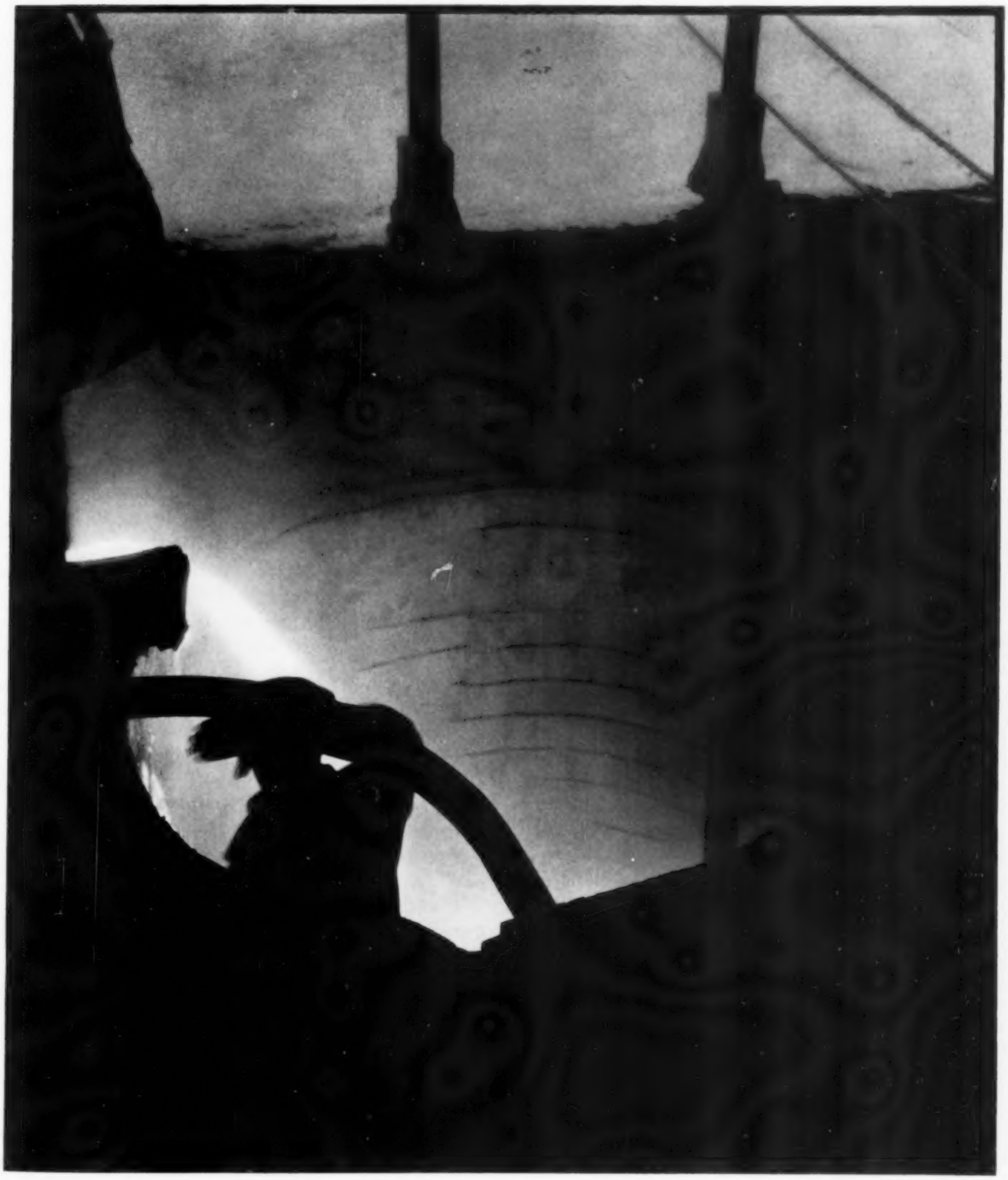
It was mentioned that there is a project on foot to start electric smelting in the Pacific Northwest utilizing power from the Bonneville Dam. It is still questionable, however, whether the cost of power will permit profitable operation in that region.

Temperature Versus Refractories

Another reportable meeting was held in Chicago late in September, as a symposium on "Acid, Basic, and Neutral Refractories", sponsored by the Chicago Section of the American Ceramic Society and the Department of Ceramic Engineering of the University of Illinois, to which members of the local sections of the A.S.M. and the A.I.M.E. were invited.

At this time, R. B. SOSMAN of the Research Laboratory, U. S. Steel Corp., discussed some

"Temperature Vs. Refractories" Is Nowhere Better Exemplified Than in the Thermal Shock to a Ladle Lining From the Rush of Openhearth Steel. Photo by Bethlehem Steel Co.



frequently neglected aspects of the contest of "Temperature Versus Refractories". High temperature in itself is not primarily a serious cause of destruction, being usually secondary to such factors as chemical reaction between refractories and slags or dusts, yet it does have some pronounced effects, both temporary and permanent.

Of these effects the speaker limited himself to those reversible and irreversible changes which occur simply as a result of exposure to high temperature and did not try to include reactions between the refractory and its environment.

There is first the reversible thermal expansion, which is the expansion and contraction of a lining, wall or arch which must be allowed for in furnace design and construction. This is not so simple a thing as the ordinary table of expansion coefficients would indicate but is complicated by a number of other variables, such as the fact that a refractory is an aggregate of grains which can move relative to each other, at least to some extent, and so give rise to irreversible and largely unpredictable changes during heating and cooling. Then there are other types of change which can alter the volume of a refractory; there may be the expulsion of some volatile constituent, or the alteration of the form of some constituent, as when quartz transforms to tridymite, or there may be inversions within a single constituent, as in the several forms of silica. Other factors are melting, sintering, recrystallization, or reaction (as in the case of the decomposition of kaolin minerals, $Al_2O_3 \cdot 2SiO_2$, to give mullite, $3Al_2O_3 \cdot 2SiO_2$, and corundum, Al_2O_3).

But what can be done to offset or minimize the effect of such changes? Once the nature of the difficulty is diagnosed, a good dose of intelligent pyrometry will aid materially. Specific examples were given in the application of pyrometry to blast furnace stoves, openhearth roofs and regenerators. For the details of such therapeutic methods and a few hints on what to do before the pyrometrist comes, the reader is referred to Dr. SOSMAN's lecture course on pyrometry recently published by the ⊕.

The next speaker was W. F. ROCHOW of the Harbison-Walker Refractories Co. who described "Service Applications of Acid Refractories". He reviewed the general uses and behavior of silica and fireclay refractories and pointed out that in some applications the chief advantage of silica over a basic refractory is its lower cost. As the cost of basic refractories is reduced they will be used more widely.

This point was brought out by R. P. HEUER of General Refractories Co., who spoke of "Basic Refractories", that is, the magnesite and chrome-magnesite materials. Though constituting but 2% of the refractories used in this country, they are now of some strategic importance since our present supplies of raw materials are practically all imported. There are, however, deposits of chrome ore in Cuba and of magnesite in the State of Washington which should make us substantially self-sufficient. Magnesia is now extracted from sea water in this country, and is used to a small extent in making refractories but only to use up the residues from the more profitable chemical market for pure oxide.

Unfired Chrome-Magnesite

Basic refractories — which ten years ago were subject to spalling, showed poor strength under load, and tended to expand and disintegrate due to absorption of iron oxide — have been greatly improved, chiefly through the introduction of better sizing, of proper mixing of chrome ore and magnesite, and through high pressure forming to give greater density. The introduction of unfired chrome-magnesite refractories is another significant advance, because the cost of these materials enables them to compete with silica brick in certain applications. The unfired products also have a relatively low thermal conductivity. Basic refractories are being used to some extent in place of silica brick in copper smelting and holding furnaces and are replacing high-alumina brick in cement kilns. About three-fourths of the basic refractories, however, go into the construction of openhearths, where they are replacing silica brick in the front, back and end walls, and in monkey walls. Basic roofs of the suspended arch type have been used on 60-ton furnaces in Europe with considerable success, it being reported that as many as 1000 heats have been made with one roof.

Such was the trend in the meetings in 1940. One wonders under what conditions and circumstances such conferences will be held in 1941. Perhaps someone will be describing the first efforts to devise a bomb-proof refractory, or perhaps we shall all be too busy to find time to attend. Well, worse things than that can happen. ⊕

By The Editor

Critical points

CONVINCED that the day of the small steel plant has not vanished, after inspecting operations at Rotary Electric Steel Co. in Detroit. (It is said to be Detroit, but you taxi over miles of prairie before reaching it; presumably all the optimistic real estate men have not yet moved to California.) Originally built to commercialize a rotary process of billet casting — of which more later — and to make steel for Detroit customers by remelting the scrap produced in their region, it became apparent that the rotary process was more expensive than the conventional ingot practice, and the price-conscious automotive industry turned thumbs down on any extra.

Independent Steel Plant Makes Good

HAROLD PHELPS, melt shop superintendent, explained how the original furnace layout, with pits sunk below ground level, has been entirely replaced with an above-grade design. The electric furnaces are on high foundations, flush with an elevated charging platform, so the casting bay floor is at general level. The charging platform has large covered hatchways through which come completely built furnace roofs. It also shelters supplies of brick and ferro-alloys. Charging with a conventional charging machine through a door is judged to be better than with a drop-bottom bucket through the roof, because it can place cold scrap against the walls, and thus protect them from excessive heat through the melt-down.

There are two furnaces, one dating from the original construction in 1933 and another quite recent. The first one was rated at 50 gross tons and the new furnace regularly melts 30 tons of all-scrap charge. Both are of the 3-phase, Heroult type, and have interchangeable roofs. They cast $1\frac{1}{2}$-ton, big-end-up ingots, with hot tops.

Planned originally to produce forging ingots with a minimum of rolling mill and finishing operations, a fair proportion of the present output is highly finished, such as cold-drawn, heat treated, turned (or ground), and magnetic inspected bars. Even a small cold mill department is able to compete with the strip from the modern continuous mills. All in all, an interesting example of a small plant, flexible in its operation, serving with small selling expense a highly concentrated and large market from which it draws its principal raw material.

MET WILLIAM H. COLVIN, JR., president, who told me the history of Rotary Electric Steel. A. J. TOWNSEND and H. M. NAUGLE, two engineers who sold their ideas and patents on continuous sheet mills at a very good price, were looking for a new toe-hold in the steel industry, and became impressed with the waste in top and bottom crop from ingot-cast metal. To them, centrifugal casting seemed a better way to produce a larger amount of sound metal in the original cast form, in reasonably small shape (and thus avoid a costly blooming mill). Their idea was to cast a heavy tire, say, 8 ft. in outside diameter, and about 6×8 in. in cross-section, the inner portion being enough thicker than the outer so that when the segments were straightened, they would be reasonably squarish billets.

First experiments demonstrated that superheated steel must be cast so there will be no overlaps where molten metal runs up on already solidified material. Consequently they moved their experimentation to the Timken plant in Canton where there was plenty of electric steel available. Using a portion of a commercial heat and casting this in their spinning mold, and rolling the billets, the resulting bars could be compared with identical material cast in vertical ingots and rolled in the ordinary way. TOWNSEND and NAUGLE thus demonstrated that their centrifugally cast steel was better and more uniform in its physical properties in all directions (free from transverse weakness); in microstructure it was also free from banding.

The Detroit plant, embodying these ideas, was built around an electric furnace, and seven centrifugal casting machines, each one to make a hoop weighing about 2 tons.

Steel Ingots, Rotary Cast

These casting machines were elephantine Victrolas. A circular plate, horizontal, mounted on a vertical shaft, was driven through a bevel gear box by a motor in a pit alongside. The lower portion of the mold itself was keyed to this rotating table. The mold was very simple, a radial section appearing like a ⊃, and slit circumferentially so that the top leg of the ⊃ would lift. A

ring of special firebrick was set into the bottom half of the mold, which not only was a "splash plate" for the entering steel, but COLVIN said also acted as a "hot top"; in other words, prevented too rapid cooling of that portion of the metal.

A gantry crane handled the ladle; a funnel directed the stream of steel to the proper place. When the mold was full, a small bin at the opposite circumference discharged enough dry fireclay to cover the inside circumference and prevented rapid solidification. One difficulty was to get the right amount of metal in this mold without underfilling or overfilling, a problem solved in a fashion by a weighing device on the ladle crane.

After solidification the top part of the mold was lifted off by crane, and the cast ring removed, sawed through completely at one point, and then sheared into billet lengths. After reheating, the first pass was a straightening pass and then rolling proceeded in a perfectly normal way.

After months of trial, it became evident that the conventional ingot practice, as a whole, was cheaper. So now, only one of the casting machines remains in place. However, President COLVIN still likes to think of the day when the peculiar excellence of the centrifugal product will be worth the price to some important application. (P.S. High sulphur, fast cutting steels crack up during cooling, when centrifugally cast.)

TRAVELING at home, to the greatly enlarged shops of Warner and Swasey, working 24 hr. daily and striving to produce one turret lathe hourly. Turret lathes of 1940 bear little resemblance to ancestral lathes of 1900; their ruggedness and micrometer precision impress this non-mechanical observer, as well as their capability of mounting 10 different tools for 10 different operations on a single piece. In this factory, long aisles of machine tools of every make emphasize the fact that it takes machine tools to make machine tools. One wonders where it started, like the old question of hen or egg — or, as Samuel Butler better expresses it, "A hen is only an egg's way of making another egg" . . . . This new shop has coordinated operations on single types of parts to such an extent that hob grinders are found among the gear hobbing machines.

One Lathe Each Hour

Striking is the number, variety and size of the gears, racks and screws that go into the main drive and the tool manipulating mechanisms. DON GURNEY, metallurgist, says that 90% of the steel parts are heat treated, and practically all of these in carburizers, salt baths or controlled atmospheres. Finish dimensions make no allowance for scaling. Much machining on gear blanks is done by carbide tools; the side of a large flat gear, after hardening, retains the fine irregular detail of tool marks that give it the appearance of a phonograph record. As GURNEY put it, "The heat treating is better than the machining." All rubbing surfaces, bores for sliding gears, faces, gear teeth, are finished by grinding. . . . . Warner and Swasey lathe beds are of nickel cast iron. Foundry work was described by F. J. DOST in METAL PROGRESS for August 1935; the ways are wear resistant enough without surface hardening. One of the small machines has flat bars of casehardened steel for ways, held down by a fine-threaded screw originally having a two-story head. The lower head is countersunk to fit the appropriate hole in the steel way. The upper head is hexagonal, for gripping with a wrench. The neck between is so designed and heat treated that it twists off at 60 ft-lb. torque. After final grinding, the set-screw heads appear as vague ghosts in the smooth ways. Unusually close control of the bar stock is necessary for uniform shearing failure rather than for any other physical property.

TO THE NEW PLANT of Moraine Products Division (General Motors Corp.) in Dayton where ROLAND KOEHRING showed me the production line for steel-backed bearings he described in METAL PROGRESS in September and the iron gears by F. V. LENEL on page 665 of November. Receipts of Swedish iron powder having been cut off since early 1940, Moraine Products is now able to produce enough for current requirements in a pilot plant — and it's good stuff, too. Millions of bronze pieces the size of a thimble or smaller are pressed of mixed copper, tin, and graphite powder, sintered in protective atmosphere, re-pressed or sized to exact shape and impregnated with oil either for lubricant or for corrosion protection. Large parts like the iron gears are made in double acting cam presses at the rate of about four a minute; small bushings for auto door hinges come from "pill machines", three per second. The pill machine has about a dozen molds or dies cut into a circular base plate. Rotating with it are a similar number of punches above, and ejector pins below, each of which is moved up or down the correct distance at the correct time as its free end engages a cam guide. . . . .

Interesting Parts Made From Powder

Interesting examples of parts made either for economical production or for special properties are: A tiny lopsided nut with countersunk central hole and all corners chamfered; a thimble of porous bronze for filtering the oil as it enters a diesel cylinder, 100% inspected for ability to pass 1 gal. of oil per min. at 25-psi. pressure; wear resistant cams pressed from iron-carbon mixtures and converted to hardened eutectoid martensite particles after sintering. Such a cam is a file-hard article

but tests only about Rockwell C-20, which is understandable if it is compared to a pile of diamonds cemented together and therefore an aggregate not very resistant to penetration.

(QUERY: Should these articles of a new method of manufacture be called "briquettes" or "compacts" or what? *Briquette* to me means "little brick", a ceramic product of non-metallic oxides; *compact* to KOEHRING means something the ladies use for their public toilettes.)

REMEMBERING EDWARD SCHROCK's interesting article last August about "Statistical Analysis of Metallurgical Problems", turned hopefully to the proceedings of a recent meeting at University of Chicago and a paper on "Statistical Analysis of Demand and Cost Functions for Steel" by JACOB MOSAK, wishing to find some light on a current problem of importance, namely, whether or not the American steel industry should expand its capacity largely and immediately. Therein read such obscure passages as: "Findings of the U. S. Steel Corp. indicate that with a given set of raw material prices and wage rates, the marginal cost of production for steel is a constant for the entire range of output experienced by the Corporation. The marginal costs may even be a decreasing function of output for that same range. It follows that with given prices and wage rates, the average costs of production are always higher than the marginal costs, and it is perfectly clear that if prices were always equal to marginal costs, as they must be under pure competition, it would be impossible for the steel industry to cover any of its overhead costs so long as the present capacity was not severely overtaxed." . . . . Oh well, maybe metallurgical phraseology would be equally obscure to members of The Econometric Society. At any rate the problem of expansion of the steel industry is still unsolved. IRVING S. OLDS, chairman of the board of U. S. Steel Corp., makes this year-end statement: "Some commentators outside of the steel industry have questioned the adequacy of existing steel capacity to take care of demands during the present emergency. To date, the nation's defense effort has not been delayed by any shortage of steel and no such delays from that cause are anticipated by the industry." Harmonize this, if you can, with such quotations as these from recent issues of *The Iron Age*: "The large volume of shipbuilding has brought about a serious delivery problem in wide plates, which are quoted from 20 weeks to the third quarter of 1941." "Chicago steel makers' bookings show a number of items virtually sold out for the first quarter." "American steel companies will start 1941 with the heaviest backlogs in their history." Steel bars and billets of openhearth carbon steels are quoted currently in Cleveland at 10 to 12 weeks delivery, S.A.E. alloy steels at 12 to 14 weeks, and electric furnace (aircraft quality steels) at even later deliveries. "No shortage," did you say?

A Bottleneck in Steel Production?

TO A FASCINATING conference on electric lighting at General Electric's Nela Park in Cleveland, that unique center of research, manufacture and merchandising. WARD HARRISON discoursed about the new fluorescent lamps, which probably shouldn't interest metallurgists because they eliminate the metallic filament. However a larger consumption of other metal is substituted, for in 30 months they have built an entirely new branch of the industry, with new buildings and equipment, which has done $40,000,000 worth of business, mostly in new installations supplementing rather than replacing existing lighting fixtures. While fluorescents are 2½ to 4 times as efficient as the filament lamps, the latter have been continually improved, so M. L. SLOAN, assistant general manager, quoted the following achievements since 1920: The price of lamps has decreased one-third, the sales have increased three-fold, the amount of light produced is up five times, but the lower cost of power and lamps has increased the national light bill no more than 50%. . . . Undoubtedly the public does not sense this constant improvement in this utility any more than it does in the telephone service; if one moves from a 1925 office to a 1940 office he is struck with it forcibly. . . . . MATTHEW LUCKIESH (pronounced Luke-ish), chief of lighting research, said that $2,000,000 had been spent at Nela Park in the last 30 years on but one line of work, the study of "seeing" — that is, the physiology of vision, the relation of light to sight. Physicians and oculists are interested only in threshold values; at Nela Park they have tried to measure visibility far beyond the threshold limits and to determine maximum visibility. The rate of blinking is as good a measure of the ease of seeing as any; the eye, in the eons of its evolution, has adapted itself to daylight in the open, where light intensity is measured in thousands of units. LUCKIESH and his researchers have concluded that an intensity of at least 100 light units is necessary for close and continuous work, if eye strain is to be avoided. Since most school, industrial and factory lighting is measured in units (10 to 15), there is a big job ahead for the promotion and sales staffs. . . . . KENNETH SCOTT described the development of the sealed beam automobile headlamp, now well known, and the study of driving in foggy weather. The conclusion of the latter work is that the light beam should be concentrated on the right curb and that practically *no* light should be thrown out

Light,— More Light

above a low horizontal plane to reflect back from fog particles into the driver's eyes. Amber light has no better fog penetration than white light, yet amber lamps outsell, five to one, clear lamps that are 20% more efficient.

DISCOVERED at least one auxiliary reason why the production of aircraft is lagging in U.S.A., when a sheaf of documents strayed to the editorial desk. The first page was an invitation to bid; then followed copies in quadruplicate of

1 Standard Government Form of Bid,

1 Continuation Schedule (2 sides, closely printed from fine type),

1 Supplement, and 1 Specification Sheet, seventeen pages in all. The specification sheet was an original document of about 400 words; it took at least an hour of somebody's time to formulate and type; it had a list of references to a mass of preceding paper work, fortunately spared us. . . . . No, it didn't relate to 10,000 propeller forgings; it was not even an order, it was a request for a bid on the delivery of one copy of a book entitled "Hardenability of Alloy Steels." The horrid suspicion flashes to mind that when the Secretary of the Navy notes that all bidders are quoting $3.50 for the item he will refer all documents, by then mountainous in bulk, to the Department of Justice for the investigation of a combination of booksellers who are maintaining prices, making identical bids, and probably restraining trade.

Uncle Sam Would Buy One Book

RECEIPT of notice that Remington Arms in Bridgeport, Conn., is abandoning cutlery manufacture to make room for small arm ammunition resurrected some months-old notes of a pleasant visit to a plant where much interesting traditional practice was mixed with modern control dictated by metallurgical research. FRANK ARNOLD, master cutler, reminisced of boyhood days in England, while expertly dismantling and repairing my favorite pocket knife. Attend, all you who sharpen knives the carpenter's way (by drawing the blade *away* from the edge over an oily stone): For final sharpening to a keen edge, use a fine carborundum stone, incline the blade at about 20° to the *dry* surface and draw three or four firm strokes *forward* against the edge, starting contact at the heel of the blade and running off at the point. The same operations on the other side give a rather blunt angle at the very edge (about 35°) and the job is done in 10 to 15 sec. BOB HENTSCHEL, head of metallurgical research for Remington Arms, says that the ordinary sharpener does most of his work back from the edge, attempting to make a slightly less acute angle than left by the grinder; nevertheless a magnified cross section of the result shows that the actual edge is rather blunt, the angle being more like 50 or 60°. It is not so "sharp" to the feel as the dry-honed 35° edge, nor so durable, nor does it test so high. Sharpness tests are made by fixing the blade, edge up, under a weighted pile of standard paper strips in the constant humidity room, and the blade drawn slowly back and forth. Linkage, stylus and motor-driven drum draw a curve of paper cut versus time, sloping down sharply at first (representing initial sharpness) but bending off toward the horizontal with time (representing durability). These tests were correlated with practice by loaning blades to local restaurants and butchers, and re-testing them after use. Blades reported "sharp", "passable" or "dull" corresponded to test curves successively lower and flatter. . . . . HENTSCHEL is confident that a high carbon, high chromium stainless blade, hardened from a high temperature, takes a sharper and more durable edge than high carbon cutlery steel (the best of which now-a-days contains about 1% chromium). Unfortunately such A-1 stainless blades are harder to sharpen, and most users and even "professional" grinders don't know how.

Sharp Knife Blades

ENTERTAINED very hospitably by ALVIN WILLIAMS and FRED CARTER at the ultra modern Newark offices of Baker and Co., pioneer American manufacturer of platinum ware. Interested in various items of platinum-lined equipment for processing highly corrosive liquids, or liquids whose metallic impurities must be limited to a few atoms per gallon. First cost of the lining is high, but scrap value is also very high. Sheets at least 0.003 in. thick are necessary for absolute safety; pure platinum linings are solderless, since platinum readily forge-welds to itself at moderate temperature. Where more thickness is necessary for stability or for resistance to collapse or blistering under a vacuum the linings are a composite platinum-base metal sheet. Gold is used as solder, its corrosion resistance being about equal to that of platinum and its melting point low. . . . . Platinum linings for pots, autoclaves and containers are merely closely fitting skins, sometimes soldered to the base metal. Small tubing starts with a disk of platinum-nickel or platinum clad steel; this is cupped by forcing through successively smaller dies down to about 1½ in. diameter; smaller sizes down to capillaries can be cold drawn from these deep cups. For larger sizes, a base metal pipe has a platinum lining slipped in and then expanded to a tight grip. Ordinarily the lining is made longer and is spun out at the flange, and the metal is soft enough to act as its own gasket.

Platinum Clad Pipe & Vessels

By C. B. Williams
Metallurgist
Massillon Steel Casting Co.
Massillon, Ohio

Small furnace with panel burners

SINCE THE DAYS of the old coal-fired pit furnaces, great progress has been made in the building and the heating of annealing and heat treating furnaces. Solid fuel has all but disappeared. Oil has been largely displaced by electricity or gas. In northern Ohio, since we have had adequate supplies of natural gas for several decades, this fuel is widely used, and the excuse for another article about a gas-fired furnace is the somewhat unique type of burner used. In the foundry where the writer is metallurgist, one of the heat treating furnaces is a small one using "radiant combustion" burners and it has given excellent results for the past two years.

This furnace has a 36×48-in. hearth, and 30 in. clearance from hearth to roof. It is lined with 9-in. insulating firebrick. The brick floor slab is 13½ in. thick, and on this are placed 4-in. cubical blocks on 12-in. centers to support a vented alloy hearth plate. Furnace bindings are ½-in. steel plate at bottom, ⅜ in. at front and rear and ¼ in. at sides, and 3-in. channels in pairs as buckstays.

A somewhat unusual number of thermocouples are available. There are seven thermocouples in the furnace, one for the automatic control and six for the recording instrument.

The control thermocouple comes through the roof in the center of the furnace, is adjustable in position, and generally extends down to near the hearth. The recording thermocouples are placed as follows: Two are 6 in. from the door on each side of furnace and 12 in. from the walls; one is in the center of the furnace 2 in. from the control thermocouple; two are in the back, 14 in. from the back wall and an equal distance from the side wall. All these five come through small openings in the roof and extend to the hearth, thus measuring temperatures at the base of the charge. The sixth thermocouple comes through the back wall 6 in. below the perforated hearth and is used to take temperatures of circulating gases at the top of the floor brick.

With this number of thermocouples in a small furnace, temperatures can be had in almost any spot. Within 60 min. after starting with an average charge (2000 lb.) for annealing, the control thermocouple will reach 1600° F. and at this time the maximum difference in the readings of the six thermocouple positions is 50° F. After say 1 hr. at heat the recorded temperature is uniform to within 5° F.

There are seven radiant combustion burners in the furnace, 9×18 in. in area, three in each side wall, as shown in the furnace drawing, and one in the rear wall, placed with long dimension horizontal. The smaller sketch shows the burner construction; the steel casting has a series of grooves in its surface leading from the gas inlet to distribute the gas-air mixture across the back of the porous brick diaphragm, which gives an even distribution of pressure at the face of the burner.

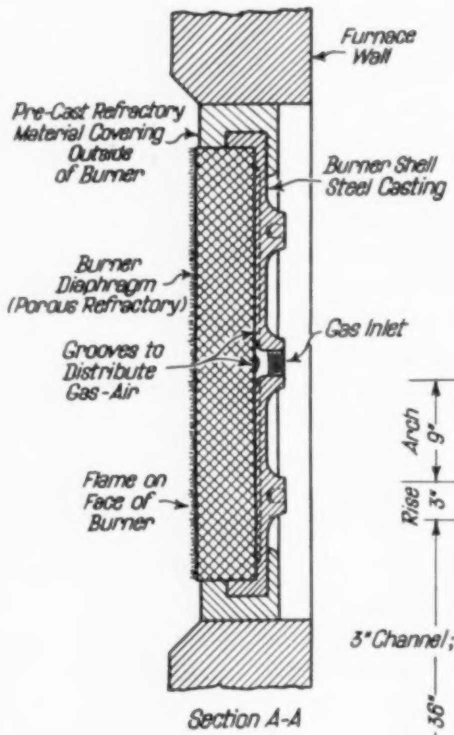
Pre-mixed gas and air is delivered to the burners through a 4-in. main with outlets of ¾ in. to each burner. This mixture is produced by a fan type of blower with packing glands on the motor side to make it gas tight. The pre-mixing assembly with proportioning valve and explosion relief is on the inlet side of the blower.

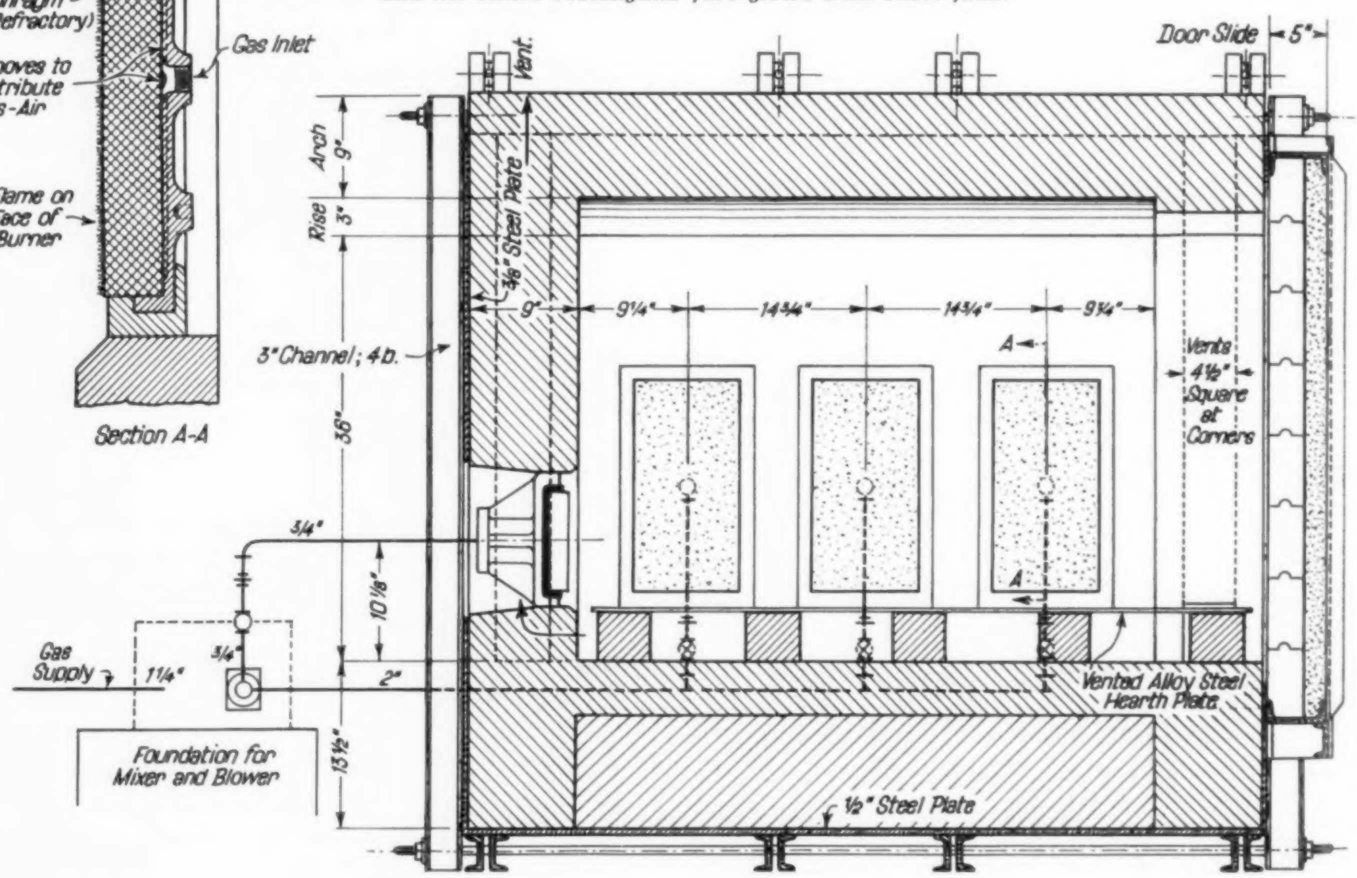
The natural gas from supply mains passes first through a pressure regulator set to 2½

oz., and then a "zero pressure governor" before it enters the proportioning valve. Here the correct amount of outside air is supplied from a 4-in. pipe, and enters the blower where the two are mixed and delivered to the burners at a pressure of 10½ oz. when the automatic control is wide open. The control has a cut-down ratio of about ten to one; a low pressure of about 1½ oz. is possible. At first this furnace was operated at 14 oz. pressure but heated a little faster than was thought desirable.

There is an electric automatic cut-off valve on the incoming gas line, so no gas can enter the blower in case of power failure. On the furnace side of the blower there is a flame arrester in the pipe line so there can be no flash-back to the blower.

At maximum capacity this supply system will deliver 35 cu.ft. of mixture per min. to each burner. The writer is not sure just how much is delivered to each burner in this furnace, but it is certainly not nearly that much. There is a turn-down valve at each burner. Thus if one side or corner of the furnace is hotter than another, the amount of fuel to a certain burner can be reduced. If the furnace is to be operated as a tempering furnace as low as 900° F., only one burner is needed, and after it is up to temperature, even this is cut down to about two-thirds of capacity. With full gas-air pressure, the length of the flame playing over the entire face of the 9×18-in. burner is about 1¼ in. Any or all burners can be cut down until the flame is barely visible.





Sectional Elevation of Small Batch-Type Furnace for Heat Treating Alloy Steel Castings. Gas-air mixture is distributed across the back of a porous refractory and the entire rectangular face glows with short flame

In the life of this furnace many adjustments to the proportioning valve have been made and samples taken of the resulting gas atmospheres. The table on the opposite page will give an idea of the different atmospheres that can be obtained.

If the atmosphere is highly reducing, it is possible to carburize a thin case on the steel but it will not be thick enough for practical applications as a hard or wear resistant surface.

The scale will also be very thin under the reducing atmosphere noted in the table.

If the control is set so an oxidizing atmosphere is produced, the scale will naturally be thicker and there will be some decarburization.

With the atmosphere in the furnace slightly reducing, there is very little decarburization. It is just visible under a microscope at 100 magnifications. The following flue gas sample was taken during an annealing heat at 1600° F., and represents very satisfactory conditions as far as surface of the treated castings is concerned: 10.6% CO_2, zero oxygen, 0.6% CO.

This furnace is very economical to operate, using about half the amount of gas of other furnaces that are now operating in our own and neighboring steel foundries on similar work. The burners produce a clean, even heat. The manufacturer says they generate infra-red rays of radiant heat which is a highly efficient and effective way of extracting the maximum heat available from a fuel and transferring it to the

Nature of Atmosphere	Gas Analysis		
	CO_2	O_2	CO
Reducing	9.8%	0.0%	1.6%
Neutral	11.6	0.0	0.0
Oxidizing	8.8	1.6	0.0
Excess oxidizing	8.6	5.0	0.0

object to be heated. However that may be, this furnace has been very successfully used for the heat treatment of numerous grades of alloy steel in charges from a few pounds up to a ton and a half.

The furnace at room temperature, with no charge in it, can be brought up to 1600° F. on the control thermocouple in 20 min., with all seven burners operating at full pressure. This is a measure of the quality of the furnace's insulation.

The highest operating temperature has been 1850° F. and the lowest 600. The longest heat was an experimental one. The charge was heated to 1650° F., held at temperature for 3 hr., and then cooled at the average rate of 70° F. per hr. down to 600° F., requiring a 15-hr. cooling cycle. The cooling rate through the critical range was 15 to 20° F. per hr.

The heat treating furnace used in the foundry has proved to be so economical and easy to operate that we intend to use similar burners, but of a different shape and size, for ladle dryers and heaters.

3.7-In. Shell Forging

An unusually detailed and well illustrated article on the above subject was published anonymously in *American Machinist* for Dec. 25, 1940, describing operations in a Canadian plant which started making high explosive shell for the British Government in 1936. The process, known as "Stewart-Lloyd", partially pierces a square billet simultaneously expanding it to a round, and later reduces the thickness of the side walls by pushing the bottle through a series of reducing rolls. The process maintains a heavy base (2 in. thick), enough to give stock for machining a recess for the baseplate cover. No machining is done on the inner cavity; after the outer contour is rough machined the nose is heated to 1830° F. in a porthole type of gas furnace and partially closed by forcing it into a tapered die; the end opening (later to be threaded for the fuse) is maintained by a suitable plug centered in the die.

Stock is 3¾ in. square, with corners cleanly beveled so the diagonal closely fits the diameter of pot on the piercing press. Steel conforms to British War Department specifications for fragmentation, and analyzes about 0.52% carbon and 0.80% manganese. Blanks are cut cleanly and squarely to 9¾-in. length with an oxy-acetylene straight line cutting machine, a single traverse cutting a series of 16 bars placed side by side on a roller table. A hand torch heats each corner just ahead of the cutting flame to prevent interruption of the action when passing from bar to bar.

Two such machines provide 100 39-lb. billets per hour to feed a large rotary hearth furnace. Billets, stood on end, are heated to 2080° F., and are scraped free of scale during a momentary pause as they are swung from furnace to piercing press. This is a 350-ton press operated by water at 1700-psi. line pressure. The upper die is a water cooled steel casing into which is fitted the die pot, round in cross section, and a stripper bar.

The bottom die consists of a hydraulic cylinder with the piston supporting four pressure pins. A circular pressure pad is mounted on top of the pins and carries a four-pronged locating pad. The pad is a sliding fit in the die pot, and also serves to *(Cont. on page 116)*

By Ernest R. Johnson
Asst. Chief Metallurgical Engr.
Canton-Massillon District
Republic Steel Corp.

Forging the stainless steels

ANY COMPREHENSIVE STUDY of forging should stress the technique of the forging operation and the equipment, as well as the finishing operations and inspection. Obviously such a discussion of the forging of stainless steel would transgress the limits of a single article. Nevertheless it is desirable to approach the subject with some remarks about the composition and properties of the steels to be forged.

These will be classified into groups of similar characteristics and these characteristics discussed briefly. With this knowledge, we will have some idea about handling these grades in the hot working operations and how to heat treat them to get the best properties from the standpoint of wear and corrosion resistance.

Stainless steels are now well known and their use increases constantly. Many forgings are made and undoubtedly the number of applications for which forgings are suitable will be greater with time. I can remember the lectures of Professor A. E. WHITE about "Special Alloys" at the University of Michigan 20 years ago. At that time, we thought stainless steels were rather novel, that they were extremely special and there would probably be just a limited demand. Little did I realize that in the coming years, my association with Central Alloy Steel Co., and later with Republic Steel Corp., would bring me in very close contact with these "specialties". I have seen them grow from a very limited application to a place where they are produced on a tonnage basis. In our district alone, at least one large electric furnace makes stainless exclusively, producing at least 2,000 tons of ingots a month, of which half goes into cold-rolled strip. We can say definitely, therefore, that stainless steels have an increasing market and we know that the applications will be more varied as time goes on.

We will limit our considerations to the usual stainless steels and exclude the chromium steels which have less than 10% chromium. The first table lists these analyses according to their present numerical designation as used by the American steel industry. For simplicity, we are not listing every modification, since many type numbers have similar properties. As shown, these grades can be put into four groups, based on inherent type characteristics.

Group No. 1: Martensitic

You will notice that the alloys in Group 1 contain chromium as the main alloying element. Usually we consider that chromium above 10% is necessary to get satisfactory stainless or corrosion resisting qualities. At this content and up to 14.0%, with carbon as low as 0.15% or less, the alloys are definitely air hardening. The critical transformation temperatures are raised, but the rates of transformation on cooling are much slower, so that even with air cooling, hardness values are close to those obtained upon oil quenching. A steel with 0.12% carbon and 12% chromium in a 1-in. round will harden to Rockwell C-35 when normalized from 1750° F. Slightly higher hardness is obtained by oil quenching. This grade, therefore, is suitable for many applications requiring a definite increase in hardness, which can be attained by proper heat treating. Common forgings of this grade are valve seats and certain cutlery items.

The addition of carbon and especially a minor percentage of nickel to this grade makes

it possible to get higher hardness values by heat treating. In fact, the latter alloy combination, Type No. 414, is rarely used annealed because of the difficulty of softening it.

Increasing the carbon makes a more hardenable alloy. Grade No. 420 with 0.30 to 0.40% carbon has been used for many years by the cutlery trades. One of the commonest forgings has been the knife blade.

Supplementing this group is the machinable type, which may contain 0.15 to 0.30% sulphur or selenium. This grade may be heat treated, but the hardness attained is generally lower than in Grade No. 410. Possibly the best known forging is the golf club head.

Group No. 2: Ferritic

When the chromium content is raised above 14%, the characteristics of the low carbon alloys are changed. There is only a slight response to the usual transformation changes which result in grain refinement and hardening; the alloy remains soft and "ferritic" — that is, of the structure of pure wrought iron. However the corrosion resistance to nearly all reagents and environments goes up with the chromium content — a typical piece of Type No. 430 containing 0.10% carbon and 17% chromium has a better corrosion resistance than any of the martensitic alloys in Group No. 1.

The lower carbon alloys cannot be heat treated to any useful degree; therefore, they are always used in the annealed state. Such alloys are usually "notch brittle" in any appreciable section (that is, have a fairly low Izod or Charpy impact test) and care must be used in their application as forgings. One satisfactory use has been the spoon for filling ice cream cones; this is generally an annealed and polished forging. They are made by the thousand.

The higher carbon analyses of this grade, containing 0.65% and 1.00% carbon, are forged respectively into the best grade of cutlery and into bearing races and special balls for oil pump valve seats. Such alloys respond readily to heat treating and are capable of developing hardness values around Rockwell C-58 to 63. Type No. 440 with 0.65% carbon is the modern improvement of BREARLEY's original stainless cutlery steel; the first stainless cutlery steel had approximately 0.35% carbon and 13.5% chromium.

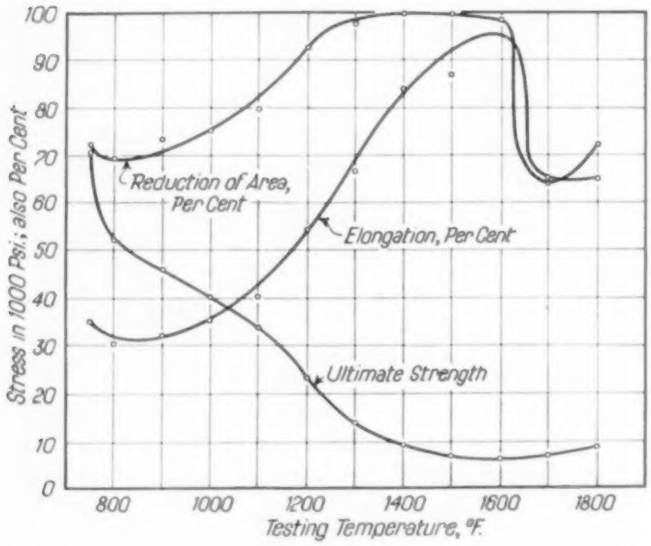
To the writer's knowledge the high chromium types with 23 to 30% chromium are not forged into any particular article. This steel is primarily for heat resisting purposes and is used almost solely in such applications. However, it *can* be forged, and is rolled into plates, bars, and a few shapes.

Group No. 3: Austenitic

Alloys of this group are totally different in characteristics and behavior from those of Groups No. 1 and 2. The addition of about 8% nickel to an 18% chromium alloy makes it

Groups and Analyses of Typical Stainless Steels

Type No.	Description of Grade	Chemical Specification					
		Carbon	Manganese	Silicon	Chromium	Nickel	Others
	Group No. 1—Martensitic Alloys						
410	Low chromium, low carbon	0.15 max.	0.50 max.	0.50 max.	10 to 14		
420	Low chromium, medium carbon	0.15 min.	0.50 max.	0.50 max.	10 to 14		
414	Low chromium, low carbon, plus nickel	0.15 max.	0.50 max.	0.50 max.	10 to 14	2.00 max.	
416	Low chromium, low carbon; free machining	0.15 max.	0.50 max.	0.50 max.	10 to 14		S or Se
	Group No. 2—Ferritic Alloys						
430	Medium chromium, low carbon	0.12 max.	0.50 max.	0.50 max.	14 to 18		
440	Medium chromium, medium carbon	0.12 min.	0.50 max.	0.50 max.	14 to 18		
446	High chromium, low carbon	0.35 max.	0.50 max.	0.50 max.	23 to 30		
	Group No. 3—Austenitic Alloys						
301	17-7 Chromium-nickel	0.09 to 0.20	1.25 max.	0.75 max.	16 to 18	7 to 9	
302	18-8 Chromium-nickel	0.08 to 0.20	1.25 max.	0.75 max.	18 to 20	8 to 10	
304	18-8-S Chromium-nickel, low carbon	0.08 max.	2.00 max.	0.75 max.	18 to 20	8 to 10	
316	18-8-S-Mo Chromium-nickel, plus molybdenum	0.10 max.	2.00 max.	0.75 max.	16 to 18	14% max.	2 to 4% Mo
321	18-8-S-Ti Chromium-nickel, plus titanium	0.10 max.	2.00 max.	0.75 max.	17 to 20	7 to 10	Ti = 4 × C
347	18-8-S-Cb Chromium-nickel, plus columbium	0.10 max.	2.00 max.	0.75 max.	17 to 20	8 to 12	Cb = 10 × C
303	18-8-FM Chromium-nickel, free machining	0.20 max.	2.00 max.	0.75 max.	18 to 20	8 to 10	S or Se
	Group No. 4—High Austenitic Alloys						
309	HCN; High chromium-nickel	0.20 max.	2.00 max.	0.75 max.	22 to 26	12 to 14	
310	NC-3; High chromium, higher nickel	0.25 max.	2.00 max.	0.75 max.	24 to 26	19 to 21	



Short Time Tensile Tests at High Temperature on Type 410 Steel; 0.10% Carbon, 12% Chromium, Show a Sharp Change of Properties at the Critical Point

austenitic, meaning that there is no critical transformation temperature range. The atomic arrangement in the metallic crystals is fundamentally different from that in the ferritic alloys, being the unstable arrangement characteristic of common steels when they are at a temperature *above* the transformation. Consequently these austenitic alloys have a tendency to change into the more stable state, and this tendency to change takes the form of a precipitation of certain compounds (usually carbides) from the austenitic solid solution — when composition, temperature and time are favorable.

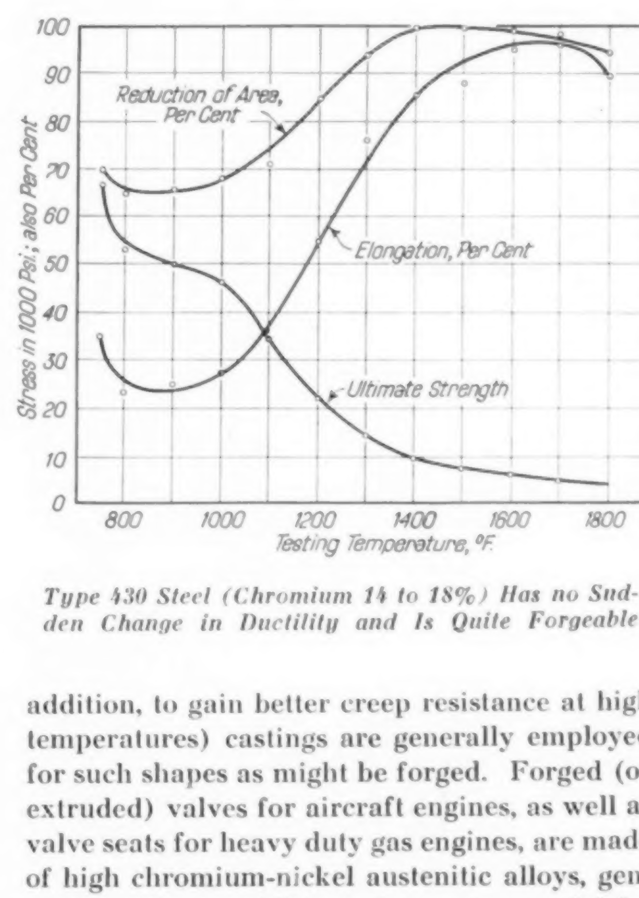
The austenitic condition, being that of hot steel, is one very susceptible to working. Annealed alloys of Group No. 3 are therefore very ductile and easily worked, even when cold. They strengthen readily by cold work; cold-rolled strip of 18-8 can easily have a strength equal to the hardened alloys of Group No. 1. Any forgings made from these alloys are generally annealed.

The lower carbon (under 0.08%) is specified when there is a possibility of incipient transformation and carbide separation, which would deteriorate their corrosion resistance. Low carbon would be specified if any of the parts might be subjected to welding and then have to resist strong corrosive media with no chance of annealing.

Elements like titanium, columbium and molybdenum are added for specific purposes. Titanium and columbium form carbides that are insoluble in austenite, thus robbing it of carbon and correcting any susceptibility to carbide separation, and permitting the metal to be welded in heavier sections without subsequent annealing. Molybdenum improves corrosion resistance; at the present time this is the best one available. Few forgings, however, are made from these latter grades.

There is a machinable grade of 18-8 termed 18-8-FM (Type 303) containing either sulphur or selenium and phosphorus. The presence of these elements makes it possible to machine the alloy at a reasonable rate. Some few forgings are made from it to take advantage of its inherent corrosion resistance and machinability.

Increased chromium and nickel contents of Group No. 4 improve heat resisting properties and such alloys are used solely for high temperature work. Forging could be done, but the general stiffness of these high alloys makes it inadvisable to do so. For this reason (and, in addition, to gain better creep resistance at high temperatures) castings are generally employed for such shapes as might be forged. Forged (or extruded) valves for aircraft engines, as well as valve seats for heavy duty gas engines, are made of high chromium-nickel austenitic alloys, generally with an addition of tungsten, molybdenum or silicon.



Type 430 Steel (Chromium 14 to 18%) Has no Sudden Change in Ductility and Is Quite Forgeable

High Temperature Characteristics

A knowledge of the hot working properties of the various alloys can be obtained by studying their high temperature strength and ductility. We usually employ tensile test pieces, heat

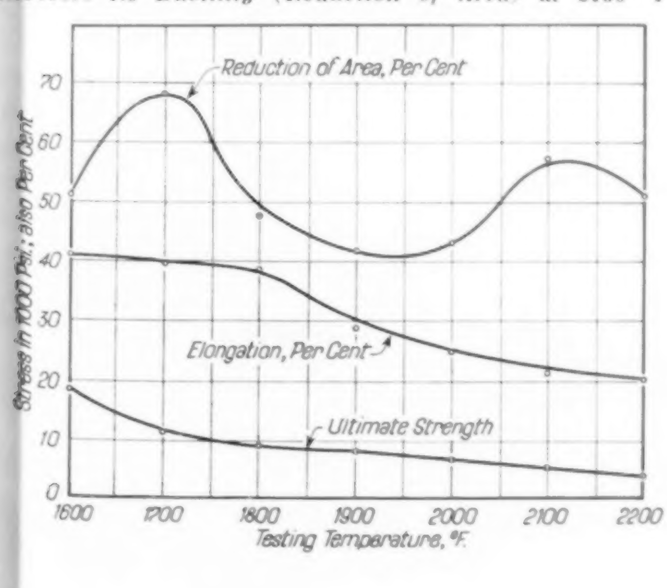
them to specified temperatures and then pull them apart, measuring tensile strength, elongation and reduction of area. The values of these "short time tensile tests" are best shown by the curves presented on these pages.

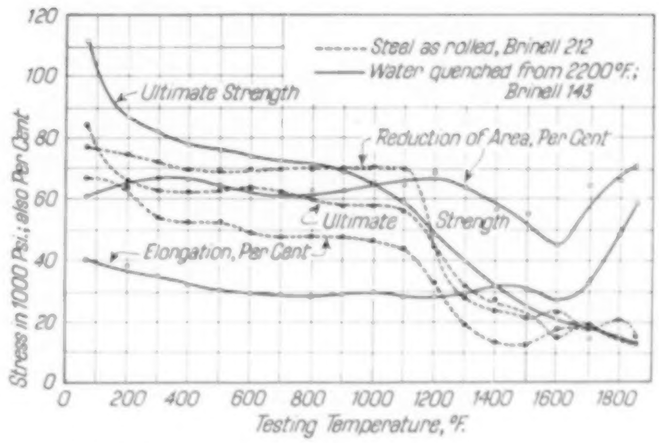
You will note in the first figure that the tensile strength of the 0.10% carbon, 12% chromium alloy decreases until 1600° F. is reached and then remains about the same as the metal changes from the ferritic to the austenitic condition. Ductility values are also at a minimum here. With even higher temperatures the tensile strength decreases and ductility increases. This chromium steel is workable at 2100 to 2150° F.

Sometimes, if the carbon is on the low side and the chromium a little high, the alloy will tend to reverse the transformation at very high temperatures, forming some delta iron, which has the same atomic arrangement as the alpha iron or ferrite stable at room temperature, but which is much harder than the austenitic gamma iron at forging temperatures. Consequently, if delta iron is formed, it may give trouble in the hot working operation. In addition, it may be necessary at times to increase the time of preheat in the neighborhood of 1700° F. in order to help form a uniform, austenitic structure. At higher temperatures grains may grow too large and cause trouble by surface checking. The higher carbon grade should be handled at a lower temperature, say 2000 to 2050° F.

The presence of sulphur in the 12% chromium free machining type raises the working

18-8 With 3% Molybdenum, Tested at Higher Temperatures, Recovers Its Ductility (Reduction of Area) at 2150° F.





Low Carbon 18-8 Has a Sharp Reduction in Properties at About 1200° F. if Tested as Rolled or Annealed

temperature; this must be done to avoid splitting, for high sulphur very definitely decreases transverse ductility. Therefore, any upsetting operations must be limited. It is also suggested that the sulphur content be decreased to 0.15% if upsetting operations are necessary.

The first alloy of Group No. 2 has the high temperature properties shown in the second chart. You will notice that the tensile strength decreases with increasing temperature and that ductility increases to a maximum with no sudden changes. This alloy is, therefore, readily forgeable. Temperatures may be 2050° F., and care is only necessary to avoid grain growth. When this occurs, the surfaces wrinkle badly and it becomes very easy to produce surface defects. The higher carbon alloys are more sensitive and should be handled around 2000° F.

Alloys of Group No. 3 have different high temperature properties. There is a definite decrease in tensile strength with temperature, although there seems to be a "shelf" on the property-vs.-temperature curves between 400 and 1000° F. A pronounced lowering of the ductility is evident at the latter temperature. Above 2000° F. and up to 2300 the ductility becomes excellent. This means that the low ductility range must always be avoided in any hot working operation. Parts can be readily forged when the temperature reaches 2200 to 2250° F.

The same general statements are true of

Wing Guided Valve, Forged With no Draft in Types 304 and 410 by Steel Improvement & Forge Co. of Cleveland

the associated types, except that forging temperatures are lower for the 18-8-S-Mo and 18-8-S-Cb. The first alloy is much stiffer and will, therefore, require more care in forging and frequent reheating to get the proper flow of metal.

This statement is also true of the alloys in Group No. 4. They are generally harder and will not flow as readily under hammer blows.

Mill Practice

Knowledge of these high temperature properties has helped us a lot in steel mill operations. We can judge which alloys to roll and those whose ingots should be "broken down" by forging. We are able to roll ingots of the alloys in Groups No. 1 and 2, but the higher carbon alloys of Group No. 2 are generally forged.

Alloys of Group No. 3, excepting 18-8-S-Mo, are rolled from the ingot. The stiffness and lower ductility of 18-8-S-Mo means that preliminary forging is more feasible. Forging operations are more flexible, for the reductions and reheatings can be carefully controlled.

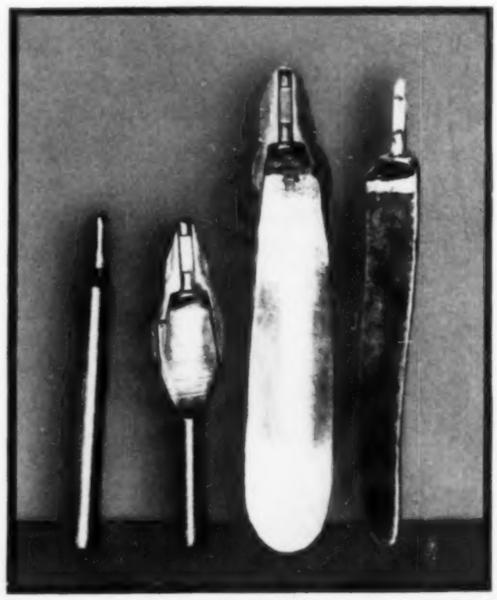
Alloys of Group No. 4 are always forged to billets or slabs from the ingot.

Tender ingots are due to the characteristic macrostructures. Long chill crystals extend inward from the surface of the ingot. Their boundaries represent planes of weakness; their natural stiffness and lack of ductility will cause the ingots to crack if the heating and reductions are not right. The original ingot structure can be eliminated by correct hot working, and a uniformly fine-grained metal produced in billet or slab. High alloys in Group No. 2 must be watched, for any grain growth that occurs after the last working cannot be corrected by heat treatment. If ferrochromium, high in nitrogen, is charged into the furnace, the nitrogen will very definitely refine the grain of these ferritic alloys. The nitrogen content will depend upon the chromium content. Higher percentage of chromium permits higher nitrogen values. We believe the nitrogen content should not be greater than 0.15%.

All of these alloys, with the exception of the austenitic grades, must be carefully handled to prevent cracking in the cooling after rolling or forging. Austenitic alloys are conveniently air cooled, since no critical transformations occur.

Billets are always surface ground, removing the complete surface, to free them of all defects. Any of these grades can then be rolled on bar mills. Some hand mills are much better than guide mills for handling the stainless grades, because galling and scoring on guides is eliminated, although more passes are generally necessary to get the proper bar size. Heating temperatures are about the same as those mentioned above as suitable for forging.

Since our plant uses guide mills, it usually becomes necessary to grind or turn many bars for forging, so that we are sure of removing all surface defects. The amount of surface that is removed will be at least $\frac{1}{16}$ in. from the diameter of small bars to $\frac{1}{8}$ in. and perhaps $\frac{1}{4}$ in. from the diameter of larger bars up to 6-in. round. Square billets or bars may be hand ground completely. Since some of the alloys of Groups No. 1 and 2 are air hardening, the bars are always mill annealed. Many of the items can be cold sheared in sizes to 2-in. round. Multiples for forging are often cold sawed.



Steps in Forging a Table Knife Include Drawing Out One End for the Tang, Drop Forging Tang and Bolster, Rolling Blade and Trimming

Forging Operations

Forging bars or billets of any of the stainless grades are conveniently cut into multiples by cold shearing or sawing when this is necessary to make individual forgings. Sometimes several forgings may be made continuously from long bars.

All grades of stainless should be carefully heated. Those of Groups No. 1 and 2 require considerable care to prevent grain growth, while those of Group No. 3 may generally be heated to a higher temperature. The alloys of

Group No. 4 will be heated to lower temperatures, say 2150° F.

Generally, a steam hammer is used for drop forgings. It will frequently be necessary to forge part way, reheat, reforge, trim or punch out centers, reheat and finish forge, and again trim. Valve seats require extreme care to get proper metal flow so that surface checks are avoided and cold shuts are not present. This means proper die design to get the correct roughing impressions so the forging will have a chance to fill the finished impression.

Sometimes forgings are made with the open frame hammer using sections of billets. Such hand forgings are easily made if the precautions regarding heating and forging temperature as mentioned previously are carefully observed.

As shown in the engraving on page 58, cutlery of the more expensive type is handled by forging the small end for the handle and the bolster under a hammer, which also flattens a short length of the blade. Then the other end is heated and rolled between forging rolls to flatten and taper the slightly wedge-shaped blade section. Trimming is done hot. Hardening, tempering, grinding, polishing, setting, and final sharpening are each an operation for highly skilled workmen. To cheapen the manufacture somewhat, a piece of carbon steel and stainless steel may be butt welded together, then the handle, bolster, and part of the stainless is forged under a hammer, then the other end is heated and the stainless is rolled between rolls to a thin section for the knife blade. Trimming is done hot and then the blade is heat treated.

Very good knives may be blanked from double-bevel flats, made in a rolling mill. This speaks well for the grain structure and other properties of the metal made in mass production. Of course such knives have no upset at the bolster; two pieces of wood or composition, riveted to the sides of the tang, form the handle. A good stainless knife requires high chromium to be stainless and high carbon to be hardenable.

Heat Treatment

Slow cooling is necessary after forging Groups No. 1 and 2, if the alloys are of the air hardening variety and the sections of substantial size. This will prevent cracking.

Forgings of Group No. 1 are either heat

(Continued on page 118)

Forging Knife Blades at Remington Arms, Bridgeport, Conn.

By Ernest V. Pannell
Manager for Western England
British Aluminium Co., Ltd.
Bristol, England

European practice in aluminum piston alloys

WHAT IS THE BEST alloy for an automobile piston? Engineers in England, France, Germany and Italy have all worked on this problem without obtaining conclusive results as yet, but the research has not been unproductive. It is an interesting generalization that while American engineers have been seeking the best alloy piston, European technicians have been developing the best piston alloy. As will be pointed out later, American metallurgists have made wide use of two or three alloys of their own development; nevertheless improvements originating in the United States have emphasized mechanical design involving slots, Invar struts, and grooves, whereas in Europe more attention has been paid to the appropriate metal or alloy. Not only have our metallurgists sought for low expansion, high conductivity, and hardness, but they have given further attention to friction and wear resistance, also the question of permanence in connection with heat treated properties. Piston alloys as studied here fall broadly into three groups: (a) Aluminum-copper (10% copper or over), (b) aluminum-silicon (12% silicon or over), (c) aluminum-copper-nickel (with 5% or less copper). All these alloys incorporate small additions such as magnesium to promote heat treatment, or manganese to improve structure.

Copper Alloys — CLERGET in Paris appears to have produced the first sand cast alloy pistons in the year 1900 using a mixture of aluminum, copper and nickel. Somewhat later such pistons were put into commercial production and fitted to engines by CHENARD-WALCKER but, it is said, without advertising the fact. The well known French metallurgist, R. DE FLEURY, devoted some study to light alloy pistons in 1913 and stated that the best alloy would have the maximum value of the expression $C \div eD$ where C is the thermal conductivity (which he thought would depend on the amount of silver in the alloy), e is the expansion coefficient and D the density. With modern piston alloys the above will have a value of from 3000 to 6000. DE FLEURY was the first to recognize the good heat properties of the aluminum piston; previously its merit was supposed to be light weight and low inertia. Little account however was taken of hardness or wear resistance.

During the period 1914 to 1918 the British National Physical Laboratory gave a good deal of study to piston alloys especially for aircraft engines. High service temperatures and loads appeared to cause burning, growth and distortion. The latter were corrected by a normalizing treatment at 750° F. for three to four hours before finish grinding. In this way change of dimensions with heat was anticipated and eliminated. "Burning" was indicated by cavities in the piston crown after a period of operation and appeared to be due to local hot spots which melted out the copper-aluminum compound ($CuAl_2$) and permitted the alloy structure around it to collapse. Inasmuch as this compound melts at about 1000° F., it is obvious that the design of the pistons in question did not allow rapid transfer of heat from the crown to the ring belt and cylinder wall. The remedy lay in heavier sections and an alloy of better conductivity. It is also suggested that the $CuAl_2$ compound was in conglomerate lumps which

would have been better distributed by more thorough chilling when cast.

As regards composition the British authorities, while maintaining the use of copper, gradually increased the percentage from 7 to 12 and later to 14, adding 1% of manganese. Hot tensile tests showed the value of this last composition as its strength increased at moderate temperature. This alloy was known as "14:1" and was later commercialized under the name of "aerolite". While it appeared that the thermal conductivity was some 20% below normal, the late Dr. ROSENHAIN proved that not only this property, but also brittleness could be ameliorated by normalizing at 750° F. Further tests were made using nickel as an addition to copper, also with good results. Since 500° F. has been shown to be a normal working temperature for the piston crown in aircraft engines the following figures for short-time tensile strength at 500° F. are of interest:

Aluminum + 12% copper	15,500 psi.
Aluminum + 12% copper + 2% nickel	19,000
Aluminum + 14% copper + 1% manganese	22,000

In the first two instances there is a reduction in tensile at normal temperature of 20 to 25%. In the aluminum-copper-manganese alloy there is an increase in this figure of nearly 12%.* Other constituents were also tried, including chromium, cobalt and vanadium, but none of these appeared to maintain strength of the alloy at high temperatures. One per cent of iron, however, when carefully introduced, maintained the hot strength at 95% of normal.

Subsequent experiments diverged toward heat treated alloys containing magnesium, either following the lead of WILM in his wrought duralumin (circa 1910) or the development of the American permanent mold casting alloy No. 122 (aluminum-copper-iron-magnesium) by T. D. STAY in 1917. All these copper alloys are susceptible of heat treatment to dissolve as much as possible of the $CuAl_2$ compound, fix by quenching and later re-precipitate by aging. In this way the fine particles of this or other compound reinforce and strengthen the individual crystals. Some authorities take the view that heat treatment cannot *permanently* improve pistons since if strength is conferred by heat it can also be impaired by heat. A leading English metallurgist states: "Pistons probably lose all hardness conferred by heat treatment after running some time and there is therefore no gain by heat treating to give hardness." Accepting this statement as correct for the heads, operating conditions in motor cars are such that American metallurgists believe that heat treatment is of permanent value to the metal at the lower ring belt, wrist pin and skirt sections.

Following the English view further, certain German metallurgists favor the use of higher percentage of copper; in this way there is a more complete network of the hard $CuAl_2$ compound *between* the crystals instead of a finely dispersed assembly *in* the crystals; they have therefore developed such alloys as "quarzal" and "zirconal". In these metals the excess $CuAl_2$ network rides higher on the surface than the softer matrix, and according to tests by PAUL SOMMER this gives better wearing properties and lower friction. It is assumed that the network will come in close contact with the cylinder wall, and the rest of the surface then provides depressions to hold an oil film.

While the copper-manganese piston alloy was developed in Britain it has largely gone out of use there. In Germany however it was taken up, the copper being increased to 15 or 16%, the manganese to as much as 6%, and iron (or other metal in the same group) added to the extent of 1%. This alloy, "quarzal", Brinells 160 cold and 98 at 500° F. Its density is high, being 3.2; expansion is stated to be below normal and its wearing resistance extremely high.

The method of testing frictional wear in Germany is somewhat involved and arbitrary and it is suggested that a useful line of research lies open in this field. It has not been established just how far friction is responsible for the heat generated in a piston, particularly in the skirt where any seizing would likely take place. However, a low friction coefficient is doubtless as important in a piston as in a bearing. It is known that nickel reduces the surface friction of an alloy, probably by reason of the better finish it confers, and the alloy "gama" used in France analyzes 12% Cu, 2% Ni.

*EDITOR'S NOTE: Short-time tensile tests on some 30 alloys, cast, wrought and heat treated, are given in Appendix C and D of "The Aluminum Industry", and in no case is the strength at 500° F. as high as the strength at room temperature. These tables show the 12% copper alloy, as cast, as having a tensile strength of 24,500 psi. at 75° F., and 18,900 psi. at 500° F. It is suggested that the above-mentioned 1% manganese alloy may have hardened by precipitation of some micro constituent during heating and testing, and that a similar test piece similarly heated but then tested at room temperature would have been even stronger.

(EDITOR'S NOTE: American experience indicates that rate of wear is seldom of importance in the successful operation of aluminum alloy pistons. They practically never fail because of reduction in skirt diameter from wear. The most usual cause of failure is collapse or permanent deformation of the spring-type piston now in general use. Wear is an even smaller factor in the rigid trunk-type piston, such as is generally used in aircraft engines, since clearances must be considerably greater than with the flexible spring-type piston. If seizure takes place, a rapid rate of wear may occur, but it cannot be said that this wear is the primary cause of failure.)

In England, too, pistons have for some time been produced in a self hardening copper alloy of good bearing properties. This has been developed by the Metal Castings Co. of Worcester and contains up to 10% copper with additions of magnesium, nickel and chromium. The Brinell hardness is 145 cold and shows little softening at operating temperature. Machining properties are particularly good and there is no trouble with "hard spots". Because of the cost and time involved in heat treatment, quenching and age hardening, there is a tendency in England toward self hardening alloys of this type which require only a normalizing treatment.

A representative series of aluminum-copper piston alloys as used in Europe is shown in the table below. Most of these have a normal expansion coefficient between zero and 575° F. of 13.5 to 14.5×10^{-6} per °F. and a thermal conductivity figure of 34 to 36% (silver = 100%). The table brings out the tendency toward the use of hard, self hardening alloys having a relatively high copper content.

Aluminum-Silicon Alloys

Shortly after the introduction of "alpax" the 12% silicon alloy, in 1920, it was tried for pistons. The metal was found to have several very useful advantages as it was ideal for permanent mold casting and, more important still, it possessed a coefficient of expansion some 20% lower than other types of alloy. On the other hand it was deficient in hardness; it had a very low proportional limit, and later tests have shown a high degree of friction in service. Keeping the good feature of low expansion this alloy has developed into a number of piston metals giving better hardness, machining and running properties. This has been achieved by increasing the silicon content in some cases to over 20% and also by the addition of hardening and heat treating elements.

Much of this development originated in France and DE FLEURY was, perhaps, the first to recommend the use of the "hyper-eutectic" metals. Tests showed that the expansion coefficient (75 to 575° F.) varied with the silicon content, from 11.6×10^{-6} at 12% Si, to 9.2×10^{-6} at 35% Si.

These higher silicon alloys begin to offer the possibility of equalizing the expansion between the piston and the cylinder wall, since it is possible to produce nitralloy cylinders or liners with a coefficient of 10×10^{-6} (gray iron having a figure of 6.6×10^{-6}). These high silicon alloys however are very difficult both to cast and machine.

Better results were achieved after the addition of copper, nickel, magnesium, silicon and other hardening elements in small amounts. This is typified by the American alloy "lo-ex", developed by Messrs. ARCHER and KEMPF, which has been widely adopted in Europe. In France however these elements have been added to a hyper-eutectic silicon mixture, an example being "alusil" with 21% silicon and small proportions of nickel and copper. This alloy has a cold Brinell hardness of 100 which becomes about 65 at service temperature; it machines well and has an expansion of slightly over 10×10^{-6} per °F.

In discussing expansion with temperature it should be mentioned that certain very extravagant claims have been made for certain alloys, such as a coefficient of 8.5×10^{-6}. This is quite impossible to achieve with any normal alloy in practice; the most favorable value for a practical piston alloy is represented by 10×10^{-6}, which figure applies to "alusil", "supra", and "K-S 280", all containing over 20% silicon.

The "diatherm" piston developed in France uses a hyper-eutectic alloy and is

Aluminum-Copper Group of Piston Alloys

Alloy	Composition (a)					
	Copper	Magnesium	Manganese	Nickel	Iron (a)	Chromium
Bohnalite	10.0	0.3	...	...	1.2	...
M. C. C.	10.0	1.3	...	2.0	...	2.5
British L-8	12.0	...	...	...	...	...
Titanal	12.0	0.8	...	...	...	...
Citroen	12.0	0.1	0.5	...	...	...
Gama	12.0	...	...	2.0	...	...
Novalite	12.5	0.3	...	1.4	...	...
G-97	12.5	0.3	1.4	...	...	...
Aerolite	14.0	...	1.0	...	...	...
Quarzal	15.0	...	6.0	...	1.0	...
K. S. Red	16.5	...	...	0.8	...	...

NOTE (a)—All the alloys carry normal amounts of silicon and iron (about 0.5% of each) except where more is shown.

Aluminum-Silicon Group of Piston Alloys

Alloy	Composition					
	Copper	Silicon	Magnesium	Manganese	Nickel	Other
Sylcum	7.3	9.0		0.5	1.4	
Panseri	1.0	11.5	0.4		4.5	
Alpax		12.0				
Alpax G		12.0	0.3	0.4		
Central A	2.5	12.0	1.3	1.3	2.5	0.2 Ti
Lo-ex	0.8	14.0	1.0		2.0	
K. S. 245	4.5	14.0	0.7	0.8	1.5	
Hypersilicie	3.0	18.0				
Citroen	1.0	19.0	0.5		2.0	
Supra	5.0	20.0	0.4			
Alusil	1.5	21.0			0.7	
K. S. 280	1.5	22.0	0.5	0.7	1.5	1.2 Co

Iron is not a desirable addition; it is assumed that about 0.5% is present as an impurity throughout.

moreover designed as a plain trunk type. Care has been taken to taper the section from a thick head down to a thin edge of skirt. To avoid distortion the section has been thinned at the piers so that the wrist pin bosses will receive as little heat as possible. This prevents distortion and tightening on the pin.

The silicon alloys appear to suffer from two disadvantages; low conductivity and relatively high friction. The former value averages 27% as against 35% for the copper alloys. This in itself means that the piston will run hotter. The use of nickel in the alloy appears to ameliorate the condition to some extent. The wearing properties are affected, according to Sommer, by the surface deformation of crystals in service. It is stated that the soft constituents of the alloy recrystallize most easily, standing out on the surface until they are worn down. This has led to the addition of as much as 5 to 7% copper in "supra" and "sylcum" alloys. Tests made by E. Koch of the Mahle Gesellschaft, Stuttgart (the largest Continental piston producers) give a figure of merit of wearing properties based on "bohnalite" at 100%. On this scale "lo-ex" shows 80% and the high silicon alloys 70%.

The remaining chief feature of this group of alloys is light weight. Density averages 2.65 as against 2.90 for most of the copper alloys.

Aluminum-Copper-Nickel-Magnesium

In the early days of light alloy pistons an alloy was used by the National Piston Co. of New York, for their production, embodying over 90% aluminum and the balance copper, nickel and magnesium. Alloys in this category termed "magnalite" appear to have originated in Germany some time earlier, but little development ensued. The proportions appear to have been a happy guess and there was no recognition of the heat treating possibilities.

As a piston material the alloy was virtually dropped in America and the study and development of this group had to wait until it was taken up by the British investigators in 1918. As already mentioned, the National Physical Laboratory metallurgists established the useful effects of adding nickel to an aluminum-copper alloy, inasmuch as the hot strength and conductivity were much improved. Further tests showed that it was possible at the same time to reduce the copper content (and the weight).

Since the heat treatment of duralumin was simultaneously being studied, it was decided to test the effect of adding magnesium to the copper and nickel and tentatively heat treating the metal; the resulting alloy was termed "Y-alloy", and was referred to at the time as "cast duralumin". It contained, as is well known, 4% copper, 2% nickel and 1.5% magnesium, and was the first cast aluminum alloy subjected to thorough metallurgical investigation.

There is on record a considerable amount of literature dealing with its constitution and properties. Owing to its complexity, involved in the many compounds of aluminum and nickel, no thorough knowledge exists even now of its constitutional changes. The main thing is that the British investigators, who had been seeking an alloy to stand up to airplane piston service, had found what they wanted.

Tensile strength of this alloy when cast in permanent molds and heat treated is of the order of 40,000 psi., and at a service temperature of 500° F. it is still over 22,000. For the same temperature range Brinell hardness falls from 100 to 65. According to some authorities "Y-alloy" has a cold hardness of 120 falling to 75 when hot, but much depends on the type and duration of heat treatment. Cast pistons are heated in an air muffle at 975° F., quenched in boiling water and held in the water for three or four hours. A longer aging period at normal temperature for some days was originally used and probably still gives the best results for large castings, but the accelerated treatment is necessary for commercial reasons.

As regards the internal constitution, it was shown by Archbutt that in spite of the 4% copper content, the hard compound $CuAl_2$ does not appear in this alloy, its place being taken by a complex Al-Cu-Ni compound in addition to $NiAl_3$ and Mg_2Si. It has already been pointed out that there is some question of the permanent

effects of heat treatment on pistons in view of the annealing effect of service temperature. Two facts stand out in connection with Y-alloy; first, the temperature of treatment is a good deal higher than that for a straight copper alloy and it can therefore be run hotter without annealing; second, this metal has a remarkable recovery value so that although some temporary annealing may take place, the alloy hardens up again at a lower temperature.

An English authority, W. C. Devereux, has advised against the deliberate heat treatment for attaining abnormal hardness. He believes that if a piston is treated to give a Brinell of 150 or over, the crown will manifestly become annealed in service leaving the lower zone of the piston hard. As a result stresses are redistributed and resulting distortion may be enough to contribute to failure. He recommends a cold hardness not over 120 for small pistons and 80 for diesel pistons, the castings being deliberately annealed to yield the last figure. An important aim is maximum strength and permanence at the wrist pin bosses.

"Y-alloy" is not easy to cast; it has a tendency to hold gas if the heat is kept molten too long, the magnesium may become partly oxidized leading to black specks, and trouble is sometimes experienced with intercrystalline cracks. All these conditions can be controlled by good foundry practice. Gas occlusions have proved the most troublesome, and have been most effectively cured by cooling a gassed heat in the pot down to the solidus temperature, then rapidly heating up again and pouring. When poured the metal should not be stirred and gates should be designed to give a quiet easy flow into the mold.

Experience with "Y-alloy" led some investigators to improve on it, and the research work of Hall and Bradbury of the Rolls Royce Co. resulted in the development of the "hiduminium" alloys, notably "RR-50" and "RR-53". For the most part lower proportions of alloy are used, together with an addition of silicon to improve foundry properties, iron to give a stronger structure and, most important of all, titanium to refine the grain. Titanium is also thought to accelerate heat treatment, prevent gas holes on solidification, and give a wider temperature range for pouring.

No group of casting alloys has been so intensively studied in England from the industrial viewpoint as "hiduminium" and as a result they dominate light alloy casting practice in Britain, particularly for high temperature service. "RR-50" is not strictly a piston alloy, this being the function of "RR-53", but it does show the first step in the transition from "Y-alloy" to the "hiduminium" series. "Ceralumin C" is another piston alloy of somewhat similar characteristics to "RR-53" except that cerium takes the place of titanium. All these alloys are standard and proprietary in Britain and elsewhere; in England they were developed for aircraft pistons but latterly these are usually forged from alloys in the same group.

An interesting line of development exists in the production of pistons in two alloys. Since the aluminum-silicon pistons are characterized by low expansion their merits are most useful in the piston skirt, while the "Y-alloy" type (with its resistance to heat and good thermal conductivity) is superior for the head. Therefore a composite alloy piston is being produced in which the mold is poured from two ladles; first with "Y" or "RR-53" and then immediately after filled up with "alusil" or other hypereutectic mixture. With the proper technique this results in a perfect bond between the two zones, and a proper amount of interdiffusion is assisted by the lower density of the silicon alloy. In some instances even pure aluminum has been employed for the head so that the full advantage of its high thermal conductivity is obtained. Such pistons are finished as a plain trunk, without slots or other mechanical device.

Piston alloys of the copper-nickel-magnesium group have an average expansion rate of 13.5×10^{-6} per °F.; their thermal conductivity is 38 to 40% of silver. According to the German authorities previously quoted, the figure of merit for wearing properties is 90% of "bohnalite" but this figure should probably be higher. The presence of nickel lends itself to a high finish after grinding and careful tests would show that the friction properties are at least as favorable as any piston alloy now in use.

Aluminum-Copper-Nickel-Magnesium Pistons

Alloy	Composition					
	Copper	Nickel	Magnesium	Silicon (a)	Iron (a)	Other
Magnalite	2.5	1.5	1.3			
Baush A-5	6.5	1.2	0.5			
Diesel	3.0	1.5	1.0			
X-Alloy	3.6	0.7	0.6	0.7	1.2	
Y-Alloy	4.0	2.0	1.5			
RR-50	1.3	1.3	0.1	2.2	1.0	0.18 Ti
RR-53	2.25	1.3	1.6	1.25	1.4	0.10 Ti
Ceralumin C	2.5	1.5	0.7	1.2	1.2	0.15 Ce

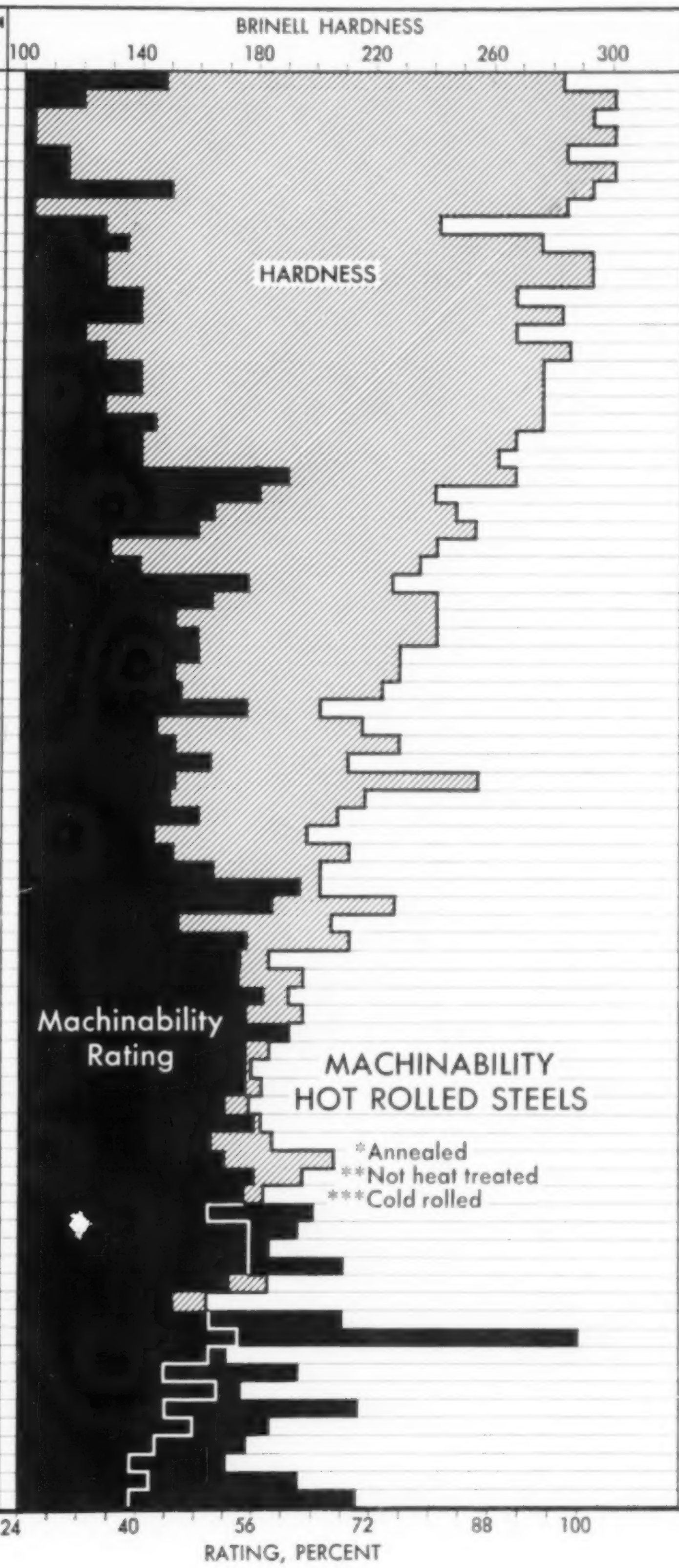
Note (a): Iron and silicon impurities are present in normal amounts except where a larger proportion is indicated.

Machinability of Hot-Rolled Steels

By James Sorenson *and* *Wallace Gates*
Chief Metallurgist — Head, Standards Dept.
The Four Wheel Drive Auto Co., Clintonville, Wis.

Relative time for removing unit volume of the S.A.E. steels in a well-equipped machine shop, averaging such variations as tools, operators, types of machines, speeds and feeds. The tools or the material generally determine the depth of cut. Courtesy Four Wheel Drive Auto Co. and *Product Engineering*

S.A.E. No.	Ultimate Strength Lb. per Sq. In.	Elastic Limit Lb. per Sq. In.	Elongation in 2 In. Per Cent	Reduction of Area Per Cent	Machining Time Index
4340	150,000	125,000	22	56	2.38
4150	150,000	125,000	18	45	3.13
3340	150,000	125,000	20	54	4.00
2350	150,000	125,000	16	42	4.00
3250	145,000	120,000	16	48	3.34
2340	145,000	120,000	18	50	3.34
4640	142,000	125,000	21	60	2.27
6150**	140,000	105,000	16	42	4.00
3340**	140,000	100,000	20	50	2.86
3140	140,000	115,000	18	48	2.64
2330	140,000	110,000	18	50	2.86
6135	138,000	120,000	20	52	2.86
5140	135,000	115,000	20	50	2.50
4140	135,000	122,000	18	55	2.50
3240	135,000	115,000	18	50	3.13
6130	130,000	115,000	20	55	2.86
4130	130,000	115,000	20	55	2.50
3312	130,000	110,000	22	58	2.50
3230	130,000	105,000	18	50	2.86
6140**	125,000	110,000	15	40	2.38
3220	125,000	95,000	18	45	2.50
3130	125,000	105,000	20	50	2.50
X1335	125,000	100,000	18	45	1.67
4640**	120,000	90,000	12	40	1.79
4620	120,000	90,000	20	58	2.00
3312**	120,000	90,000	22	55	2.08
3250**	120,000	95,000	18	45	2.78
9260*	115,000	82,000	18	42	2.50
4820	115,000	75,000	20	50	1.82
4615	115,000	88,000	20	60	2.00
3120	115,000	90,000	19	60	2.225
2320	115,000	88,000	20	55	2.08
2315	110,000	84,000	22	60	2.08
9255*	110,000	80,000	20	44	2.225
5140**	110,000	85,000	20	50	2.175
4815	110,000	80,000	20	50	1.82
3340*	110,000	90,000	22	58	2.38
2515	110,000	68,000	30	65	2.225
2350*	110,000	80,000	22	45	2.00
1040	110,000	90,000	18	45	2.225
3250*	108,000	80,000	22	50	2.27
6150*	105,000	75,000	24	50	2.08
3450	105,000	75,000	22	52	2.38
3240*	105,000	75,000	24	50	2.225
6140*	100,000	70,000	25	55	2.00
4640*	100,000	85,000	18	45	1.61
4340*	100,000	80,000	25	60	1.725
1095*	100,000	60,000	22	45	2.225
1035	100,000	70,000	24	55	1.82
6135*	95,000	65,000	18	50	1.85
4150*	95,000	70,000	25	56	1.85
3140*	95,000	65,000	22	55	1.75
2340*	95,000	66,000	25	58	1.82
1030	95,000	65,000	24	55	1.67
4820*	92,000	65,000	25	60	1.82
6130*	90,000	60,000	25	60	1.82
5140*	90,000	55,000	25	55	1.82
4815*	90,000	70,000	28	65	1.92
4140*	90,000	65,000	28	58	1.79
3312*	90,000	75,000	28	62	2.00
3230*	90,000	65,000	25	54	1.92
3130*	90,000	60,000	30	55	1.79
6120	85,000	65,000	30	60	1.85
4620*	85,000	56,000	30	60	1.56
4130*	85,000	60,000	30	65	1.61
2330*	85,000	62,000	26	58	1.725
1040*	85,000	50,000	22	54	1.47
3220*	80,000	68,000	28	60	1.92
2515*	80,000	65,000	32	70	2.225
1035*	80,000	48,000	28	58	1.47
1112***	80,000	60,000	15	40	1.0
6120*	78,000	60,000	35	70	1.92
4615*	78,000	48,000	33	65	1.61
2320*	76,000	58,000	30	60	1.85
1030*	75,000	45,000	28	60	1.43
2315*	74,000	55,000	32	62	1.725
3120*	70,000	60,000	32	65	1.82
1020	65,000	40,000	32	60	1.92
X1020	62,000	48,000	30	58	1.61
1120	55,000	41,000	32	60	1.43

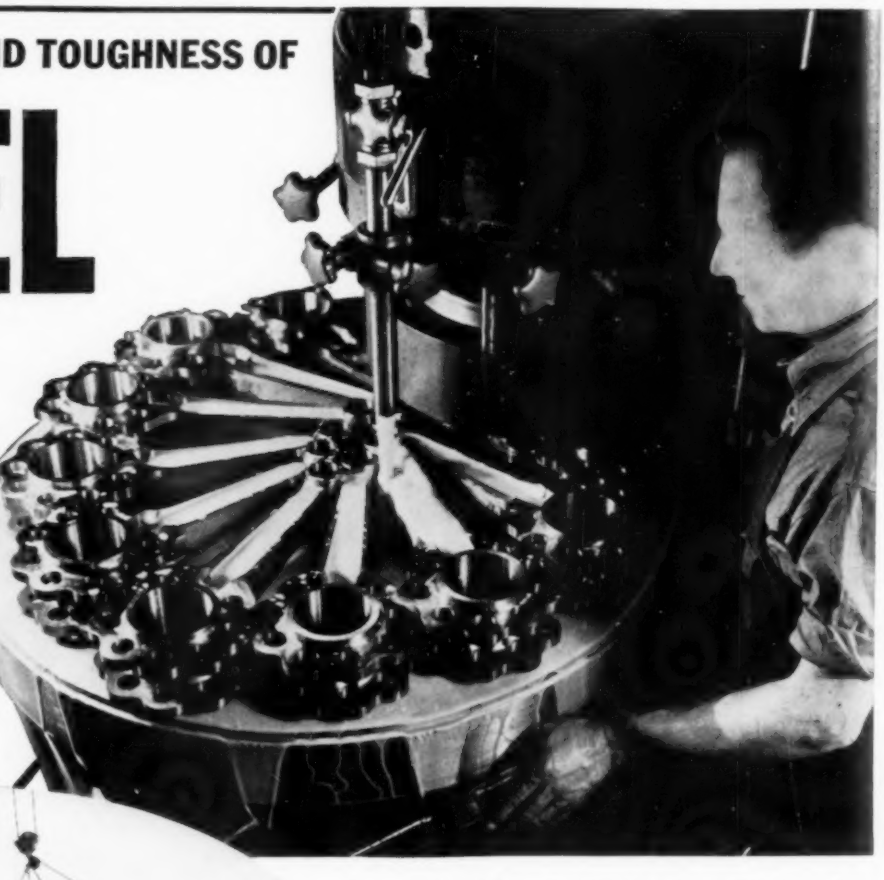


Safe DEFENSE against breakdowns . . .

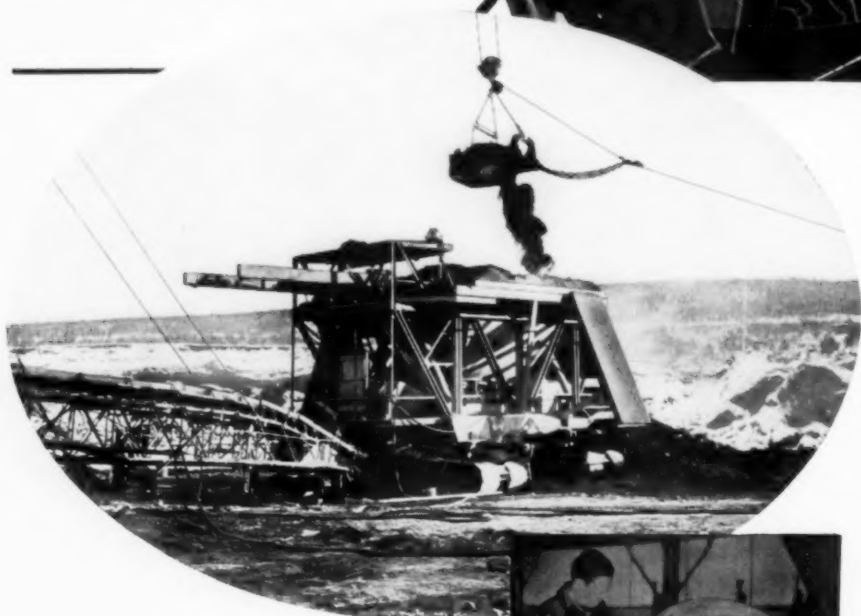
INCREASED STRENGTH AND TOUGHNESS OF

NICKEL

ALLOY STEELS



NEW JERSEY—Compactness, light weight, high strength and fatigue resistance are life-and-death requirements for aircraft engine parts. Here you see connecting rods of Nickel-chromium-molybdenum steel machined at the Paterson, New Jersey, plant of WRIGHT AERONAUTICAL CORP. Through their uniform response to heat treatment and ready machinability at high hardness, Nickel alloy steels simplify production.



ALASKA—Stripping 60 million cubic yards of frozen soil from 16 million cubic yards of gold bearing gravel is the job of this Bucyrus-Monighan electric drag line and BUCYRUS-ERIE traveling feeder. Working near Fairbanks, Alaska—more than 2,000 miles away from replacement parts—embrittlement and breakage at subzero temperatures must be avoided. More than 17 tons of $3\frac{1}{2}\%$ Nickel low carbon steel forgings were used, chiefly for shafting. Three tons of 1.50/2.00% Nickel steel castings are also employed. Gears, pinions and crawler parts are heat-treated Nickel-chromium steel. The mile long conveyor belt system, furnished by the PACIFIC CAR & FOUNDRY CO., depends on speed reducer shafts of tough Nickel-chromium-molybdenum steel, SAE 4340.

NEW YORK—Cost records show this power-driven INGERSOLL-RAND Impact Wrench 6 to 8 times faster and more efficient than hand methods for applying and removing nuts. The hammers and anvils which withstand up to 1100 torsional impacts per minute are Nickel-chromium-molybdenum steel. Nickel alloy steel is readily hardened to prevent battering and stoutly resists wear and fatigue.

• • •

AVOID BREAKDOWNS and costly delays by specifying new equipment and replacement parts in tough, shock-resisting Nickel alloy steels. For practical information about recommended applications of Nickel alloyed materials, please address:

THE INTERNATIONAL NICKEL COMPANY, INC. **67 WALL STREET NEW YORK, N. Y.**

Correspondence

Accidents Frequently Due to Unique Conjunction of Circumstances

WE have received the following from Professor PORTEVIN:

"Events prevent me, at the moment, from corresponding with my secretary who has remained in Brittany with the *Revue de Metallurgie*. Consequently I do not know whether the enclosure duplicates something already sent you. This note is written at Angoulême, near Bordeaux, on June 28, the very day that this city is being occupied by the Germans."

AT THE TIME of the collapse of the Hasselt Bridge, on the Albert Canal, I pointed out (METAL PROGRESS, May 1939, p. 491) the multiplicity of causes or possible sources of such an accident, and noted that only a careful experimental study, a thorough and well-informed survey, would determine its true cause. It was also noted that there might be several simultaneous or overlying causes. This has frequently been my conclusion following investigation of many widely varying accidents, examples of which are given below:

1. *Corrosion of Stainless Steel Tanks for Nitric Acid* — Tanks made of 18-8 steel plates assembled by welding corroded deeply all along the seams, the metal becoming brittle and rapidly unfitted for service. Moreover, a thin, gelatinous coating formed on the surface of the metal which was recognized as containing alumina. A study of the metal (and the acid it contained) led to the following conclusions:

(a) Presence in the nitric acid of traces of aluminum in the form of dissolved aluminum nitrate and colloidal alumina, derived from aluminum apparatus with which it was previously in contact.

(b) Presence in the stainless steel of an abnormal titanium content (1.35%).

(c) Welding performed with filler metal containing no titanium.

As shown by micrographic and mechanical examination, a brittle martensitic zone existed along the edges of the weld, and this was corroded by the acid. For this phenomenon to occur, however, the *triple condition* enumerated above was necessary; if the steel had not contained an abnormal percentage of titanium, or if it had not been welded with rod of different composition, or if the acid had not contained some aluminum, the corrosion would not have occurred. Each cause, taken separately, would not have been responsible for the damage — none of them is the sole cause of the trouble, only their combined effect.

2. *Failure of a Large Diameter Pipe in a Hydro-Electric Plant* — This failure flooded the plant and killed half a score of victims. A very thorough and exhaustive survey proved that the accident was the result of the following series of errors and circumstances:

(a) Unauthorized assembly of piping by welding.

(b) Very poor execution of the welding.

(c) Entirely insufficient repair of the part after finding a leak in the hydraulic control.

(d) Lack of an automatic safety device.

(e) Insufficient mechanical strength of the "safety device" actually installed.

If only one of these errors had been omitted, the accident would not have happened or would have had no serious consequences; thus, each of them is a *necessary cause* of the catastrophe, but none is a *sufficient cause.*

3. *Collapse of Belgian Bridges on the Albert Canal* — Let us consider now the collapse of the Hasselt Bridge in 1938, which was followed, at the end of January 1940, by accidents to four similar bridges on the Albert Canal. All these failures presented the common characteristic of fracture without deformation

of a metal that was either specifically or globally brittle (that is to say, having either insufficient elongation or loaded with locked-up internal stresses or strains).

We now find that these accidents probably are due to the coincidence or superposition of several causes, notably the following:

(a) A design that was indeterminate in character, or one whose stresses transcended the ones indicated by static analysis (*hyperstatique*); certainly one not well designed for welded joints.

(b) A concentration of welds and sequence of welding introducing considerable internal strains or stresses.

(c) Poor weldability of the metal used, inducing specific brittleness of the base metal and the welds, particularly at low temperatures.

(d) A very severe winter with temperatures as low as zero Fahrenheit.

It is equally probable, in this case, that suppression of one of these causes would have prevented the accident; each is a necessary condition and, consequently, is responsible, but none of them is a sufficient condition and none can take the total responsibility. It is not even easy to make a fair distribution.

Thus it is shown by the above examples that a single technical defect, a single error in fabrication or construction, a single abnormal circumstance, is usually not enough to cause an accident. Happily this is true from the viewpoint of security, for it rapidly diminishes the probability of accidents. But the accumulation and superposition of defects and errors may occur during the life of structures made by man as well as in the life of man himself, provoking accidents on the one hand, calamities on the other.

ALBERT M. PORTEVIN

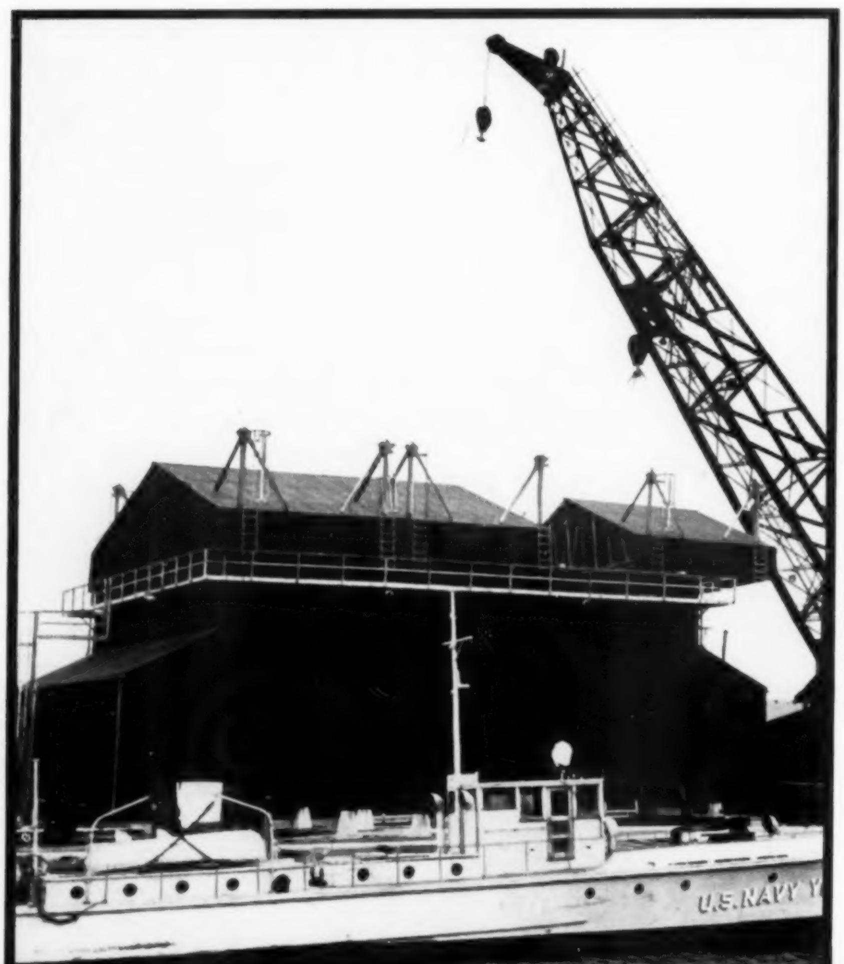
Equilibria in the Fe-Ni-Cr System Involving the Sigma Phase

BARBER, *N. J.* — A ternary equilibrium diagram of the region comprising the sigma phase was proposed by JOHN S. MARSH in the March 1939 issue of METAL PROGRESS. The available experimental material allowed only two probable conclusions of a qualitative nature: *(a)* The sigma phase occurs over relatively wide composition ranges of the ternary system and *(b)* nickel probably increases the maximum temperature of stability of the sigma phase. The diagram of MARSH was based on these two requirements, and on the fairly well established boundaries of the sigma phase in the binary Fe-Cr system.

It seems, however, that this diagram is not the only possible one satisfying the above requirements, and the present writer believes that it implies additional restrictive assumptions for which no explicit justification is given.

It seems preferable that the systematic collection and ordering of further experimental material be guided by a tentative diagram of the most general type compatible with the data already available. Further specializing restrictions should then be applied only as required by new evidence.

A somewhat more general type of diagram, complying with the same requirements which were explicitly given as the basis of the diagram of MARSH, is schematically described in the following. The boundaries of the sigma phase proper are the same in the proposed new diagram



Surface Combustion Corp. Has Built Two Mammoth Stress Relieving Furnaces for the U. S. Navy. A crane is removing one section of the roof. Internal dimensions are 56 ft. long, 48 ft. wide, 30 ft. high. It is capable of heating a 340-ton charge to 1250° F. in 36 hr. by means of recirculating air through four external heaters

(Fig. 2) as they were in the old one (Fig. 1). K is the transformation point of the compound in the binary Fe-Cr alloys, and as such is a singular point. While Fig. 1 assumes that this singular point extends into the ternary system as singular line K-K_1, in the new diagram K-K_1 is simply a line of two-fold saturation of the sigma phase. The two phases with which sigma is here saturated are α_1 and α_2 along lines K-A_1 and K-A_2, which are also lines of two-fold saturation. The ruled surfaces between the lines K-A_1, K-A_2 and K-K_1 delimit a three-phase equilibrium field. At the low temperature end,

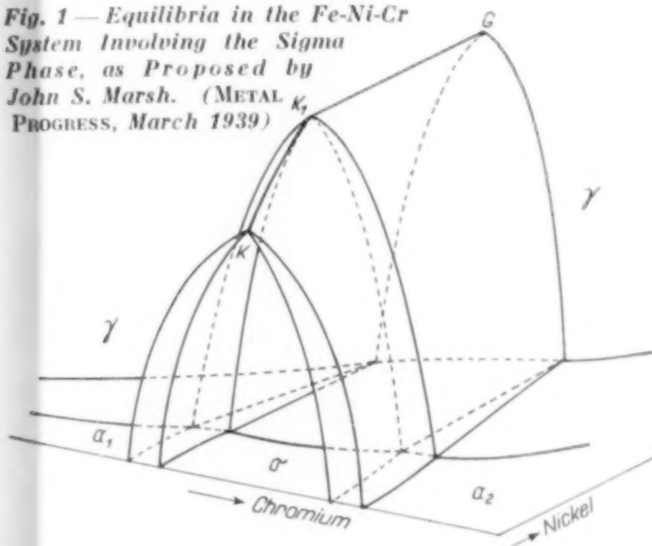


Fig. 1 — Equilibria in the Fe-Ni-Cr System Involving the Sigma Phase, as Proposed by John S. Marsh. (METAL PROGRESS, *March 1939*)

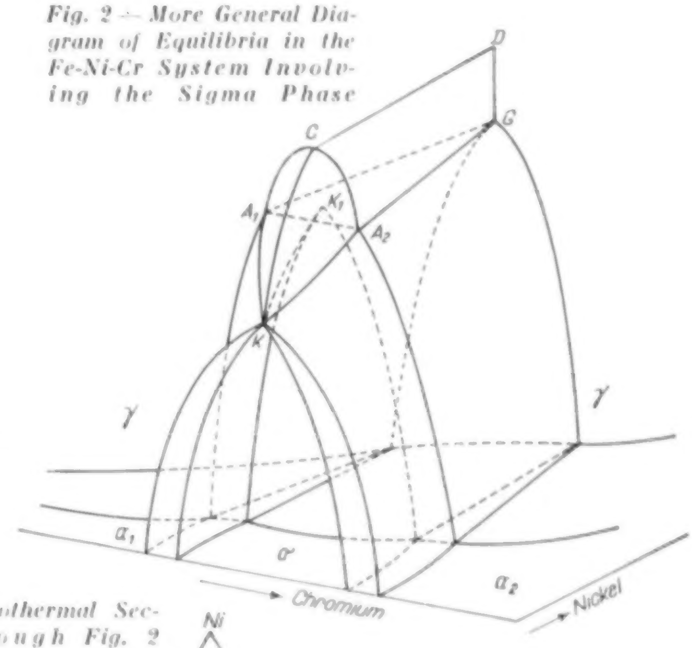


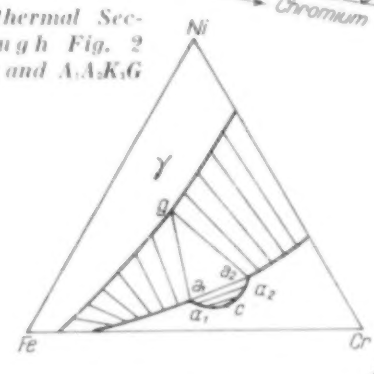
Fig. 2 — More General Diagram of Equilibria in the Fe-Ni-Cr System Involving the Sigma Phase

this three-phase field degenerates into point K, as required by the singular point in the binary Fe-Cr system. At the high temperature end the three-phase field terminates in a more conventional manner at the non-variant four-phase equilibrium $A_1A_2K_1G$. The other three-phase fields terminating at this four-phase equilibrium are $\alpha_1 + \sigma + \gamma$, $\alpha_2 + \sigma + \gamma$, and $\alpha_1 + \alpha_2 + \gamma$. The $\alpha_1 + \alpha_2 + \gamma$ field extends toward higher temperatures, and terminates at the non-variant equilibrium C-D, where phases α_1 and α_2 become identical in the critical point C. The two-fold saturated line of the γ phase in equilibrium with α_1 and α_2 ends at point D. Above this temperature there are only two stable phases: α and γ. The surfaces K-C-A_1 and K-C-A_2 delimit a two-phase field where α_1 and α_2 are in equilibrium. This two-phase field terminates along the critical line K-C, where the two phases become identical.

It is clear that the diagram of MARSH can be derived from Fig. 2 as a special case, in which it is assumed that lines K-C, K-A_1, K-A_2 and K-K_1 will coincide. In that case points C, A_1 and A_2 will coincide with point K_1 of Fig. 1; the three-phase field $\alpha_1+\alpha_2+\sigma$ and two-phase field $\alpha_1+\alpha_2$ will degenerate into line K-K_1.

In order to further clarify the difference between the two diagrams, two isothermic sections are given. Figure 3 shows an isothermic section of the new diagram at a temperature between the non-variant equilibrium C-D and the non-variant equilibrium $A_1A_2K_1G$. The triangle a_1a_2g is a section of the three-phase field

Fig. 3 — Isothermal Section Through Fig. 2 Between C-D and $A_1A_2K_1G$



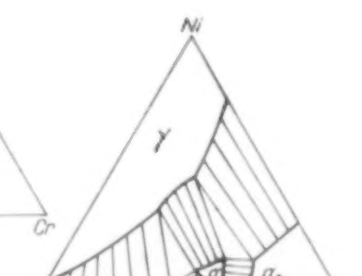


Fig. 4 — Isothermal Section Through Fig. 2 Between $A_1A_2K_1G$ and K

$\alpha_1 + \alpha_2 + \gamma$. Of the bordering two-phase fields $\alpha_1 + \alpha_2$ terminates in point c where the isothermic plane intersects critical line K-C. Figure 4 shows an isothermic section of the new diagram at a temperature between point K and the non-variant equilibrium $A_1A_2K_1G$. The triangle a_1a_2s represents an isothermic section of three-phase field $\alpha_1 + \alpha_2 + \sigma$. The two-phase field $\alpha_1+\alpha_2$ also

appears in this section. In the corresponding isothermic section of Fig. 1 the triangle a_1a_2s and the two-phase field $\alpha_1 + \alpha_2$ would disappear, and points c and s would coincide. Isothermic sections of the two diagrams at temperatures below point K are identical.

The actual diagram of the Fe-Cr-Ni system will have to be determined experimentally. Experimental decision between the two diagrams should be possible, since the co-existence in any one alloy of two alpha phases is permissible only according to the new diagram. Such decision may however be difficult by either microscopic or X-ray methods if the compositions of the two alpha phases are relatively close to each other. Another method of deciding between the two diagrams may be based on the following observations: If the new diagram is correct, alloys of a composition near point K_1, which can be homogenized to consist only of the sigma phase, may be transformed into a mixture of α (more precisely $\alpha_1 + \alpha_2$) and γ by heating slightly above the non-variant temperature. On the other hand, if the diagram of MARSH describes the conditions correctly, heating of a homogeneous alloy will yield only the α phase with no admixture of γ.

Decision of this question would have some interest from a fundamental point of view. As far as the writer is aware no ternary system is known to show congruent melting or transformation (that is, identical composition of the two co-existing phases and a definite transformation temperature instead of temperature range) over a more or less extended continuous domain of compositions. Should the diagram of MARSH prove correct, line KK_1 of this diagram would represent such a congruent domain.

PAUL A. BECK
Research Department
American Smelting & Refining Co.

Mr. Marsh Comments: — Despite the ingenuity of Dr. Beck's diagram, I feel that the one proposed by me (and simultaneously by Schafmeister and Ergang in *Archiv für das Eisenhüttenwesen*, March, 1939) is the more likely. It seems sufficient here to cite one of the several reasons for this belief: It is a matter of observation that sigma phase invariably appears as a product of alpha phase; that is,

$$\alpha \rightleftarrows \sigma$$

Beck's diagram, at point K_1, shows conditions to be $\alpha_1 + \alpha_2 + \gamma \rightleftarrows \sigma$

This I doubt, because of the before-mentioned matter of observation. It is granted that more experimental work could be used, but I believe that enough is now known to permit evaluation of the probabilities.

JOHN S. MARSH

Two Errors

JOSEPH B. KUSHNER writes that he carelessly credited JOHN WRIGHT with the discovery of bright silver plate. JOHN WRIGHT was an inventor friend of the Elkingtons, but the worker who actually contaminated the bath with carbon disulphide was named WILLIAM MILLWARD. (Page 781, December 1940 issue.)

BRUCE W. GONSER caught THE EDITOR misquoting JOE FOX in *Critical Points*, September 1940, page 269. The high strength brass, die cast, has the composition 83 Cu, 10 Zn, 5 Si, 1 Mn and 1 Al, instead of the 1% Si stated. The high silicon is very important, since it reduces the melting range below that of other brasses proposed and used for die casting.

Properties of Materials Coated With Acid Resisting Steels

KREFELD, GERMANY — In METAL PROGRESS for September 1940, W. RÄDEKER reported on the "Use of Clad Metals in Germany". This letter noted that the chemical industry is making wide use of acid resisting metals, particularly 18-8 Cr-Ni steel, as coating materials. It is well to consider further the properties of the composites.

The base metal usually chosen corresponds to the composition of boiler plate No. I (with less than 0.10% C) or boiler plate No. II with slightly higher carbon. Several acid resisting steels have been utilized as the coating material, including, in addition to the 18-8 steel, the 17% Cr steel, the Cr-Mo steel containing 17% Cr and 1.5% Mo, and the 18-8-2 Cr-Ni-Mo steel. Composition and tensile properties of the base and coating metals are given in the first table.

It will be noted that the tensile properties of the metals which are to be joined are widely different. It then becomes a question of what tensile properties the clad metal will possess. We find that we can compute it simply from the proportionate thickness. This has been proven by a number of experiments. The table opposite gives an example of an 8-mm. sheet clad with a layer of 18-8 steel.

Composition and Properties of Materials Used for Coating

Type	Chemical Composition							Tensile Properties	
	C	Si	Mn	Cr	Ni	Mo	Other Elements	Strength, Psi.	Elongation (a)
				Base Metal					
Boiler plate I	0.10	—	0.60	—	—	—	—	50 to 62,000	>25
Boiler plate II	0.12	0.30	0.60	—	—	—	—	58 to 70,000	>22
				Acid Resisting Steel					
Cr steel	0.10	0.25	0.50	17	—	—	Ti	70 to 92,000	>25
Cr-Mo steel	0.10	0.25	0.50	17	—	1.5	Ti	78 to 92,000	>22
Cr-Ni steel	0.10	0.25	0.50	18	8	—	Cb, Ta, Ti	85 to 105,000	>45
Cr-Ni-Mo steel	0.10	0.25	0.50	18	9	2.0	Cb, Ta, Ti	85 to 105,000	>40

Note *(a)*: Per cent elongation on gage length equal to 5 diameters of test piece.

The high alloy steels have lower thermal conductivity than iron or the low alloy steels. The question is therefore often raised as to what thermal conductivity the clad metal will possess, that is, whether the passage of heat from the iron to the coated layer will be hindered by the bond. Here also we can follow the same rule — the thermal conductivity depends on the thickness of the coating. The table above gives the heat conductivity up to 300° C. for an overlay of 10 to 20% 18-8 Cr-Ni steel on mild steel. As shown by experimental compared to calculated values, the boundary layer provides no obstruction to the transmission of heat, for the good adhesion of the two layers guarantees free heat transfer. This phenomenon is an advantage in such things as containers heated from without or steam-jacketed pipe lines. Heat transmission and heating power are therefore better with a clad metal than with solid high alloy steel of lower conductivity.

Thermal Conductivity of Clad Metals
(Rädeker and Schöne)

Material	Thermal Conductivity Cal./Cm./Sec./°C.			Specific Heat 20 to 100 °C.
	20° C.	100° C.	300° C.	
Base metal	0.14	0.13	0.10	0.105
18-8 Cr-Ni steel	0.05	0.05	0.05	0.120
Clad metal				
10% overlay	0.13	0.12	0.09	0.107
20% overlay	0.12	0.11	0.09	0.109

In choosing a base metal corresponding to the composition of boiler plate No. I or II, it can be seen that the tensile properties do not approach those of clad 18-8. If such a choice is made, it is done for the following reasons:

1. The material for chemical apparatus construction is generally mild steel, since it combines good mechanical properties with good workability, either hot or cold; it can be bent and flanged and, most important, it can be welded. It does not, however, fill all requirements since it lacks good corrosion resistance. By combining it with acid resisting steel in the form of clad metal, we obtain what is essentially an iron with high corrosion resistance. It is not at all necessary to endow this iron with higher tensile strength.

2. If for some special reason higher tensile strength *is* desired, it is not, however, feasible simply to raise the carbon content of the base metal. It has been found that at high working temperatures carbon diffuses slowly between the base metal and the high alloy steel coating. This can be regarded as a good indication of the

Tensile Properties of Clad Metals
(Rädeker and Schöne)

Material	Thickness	Tensile Properties at 20° C.		
		Yield	Ultimate	Elongation
Base metal				
Boiler plate I	0.283 in.	30,000 psi.	53,500 psi.	25.8%
Coating material				
18-8 Cr-Ni steel	0.031	40,000	88,000	47.5
Clad metal				
Experimental values	0.315	31,300	57,100	27.2
Calculated values	—	31,000	56,600	27.3

adhesion between the base metal and the coating, but it is a disadvantage in that if the carbon diffuses into the coating the tendency of the corrosion resisting steel to grain boundary disintegration would be intensified, since the amount of carbide-forming elements present, such as columbium, tantalum or titanium, would no longer be sufficient to combine with all the carbon and convert it to a harmless form. The higher the carbon content of the base metal, the more rapid the diffusion into the coating and the sooner the permissible carbon content will be exceeded at the exposed face.

If higher tensile properties in the base metal are desired, then the lower alloy steels may be selected, such as the nickel steels, chromium steels, chromium-copper steels, or chromium-molybdenum steels, which are already used for boiler construction. The choice of these can be made, as noted by Mr. RÄDEKER in his communication, on the basis of providing still other properties desirable for the intended use, such as better heat resistance, resistance to attack by hydrogen, resistance to embrittlement at low temperature, or creep resistance.

Present-day metal coating is not confined to the acid resisting steels but is likewise entering the field of heat resisting steels. Heat resisting steels are clad not only with mild steel, but also with other heat resisting steels in order to obtain properties not otherwise possible.

The table below shows various clad materials now used in Germany. Possible combinations are much more numerous than those given.

H. HOUGARDY
Research Department
Deutsche Edelstahlwerke A.G.

Composition Molds for Casting Novelties

CRANSTON, *R. I.* — Since METAL PROGRESS has devoted some attention recently to die casting and to centrifugal casting, readers may be interested in a newly developed adaptation of a centrifugal process for the manufacture of jewelry parts and novelty items. They are cast of a low melting point alloy of tin directly in the rubber molds, the rubber being of such composition as to resist successfully the molten alloy for a large number of casts.

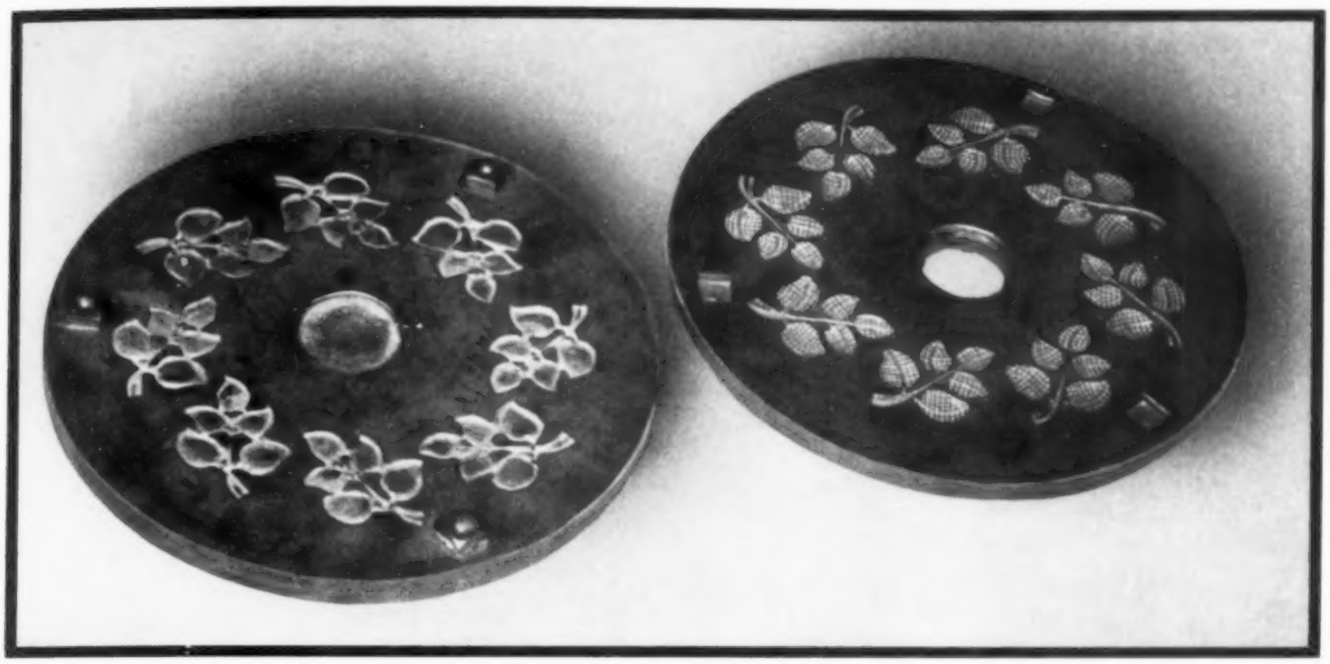
A view of a mold for casting simultaneously eight leaf designs is illustrated. (This is before the gates are cut.) The mold is produced by placing models of a suitable material between two unvulcanized discs of solid compound. The assembled unit is placed in a simple vulcanizing press whose platens have been previously heated to the required temperature, and pressure up to 36,000 lb. exerted. After curing for approximately 45 min. the pressure is released, the mold removed and split. The split mold is shown in the photograph having the mold with the leaf motif. Gates are now cut from the cavity to the center to permit the flow of metal.

Such rubber molds cost less than 10% the cost of bronze molds previously used. They are suitable for casting metals having a melting point up to 700° F. on a production basis. From 15 to 100 gross of castings can be produced from a mold costing less than $5. Perfect reproduction is assured by use of centrifugal force to distribute the molten metal. The resulting castings retain fine detail, have smooth texture and are free from blow-holes. From one to 72 pieces

Clad Materials With Special Properties

MATERIAL	C	CR	NI	MO	OTHER ELEMENTS	SPECIAL PROPERTIES
Base Metal: Cr-Mo steel	0.10	2.5	—	0.5	—	Resistant to hydrogen; better high temperature strength than iron.
Overlay: 18-8 Cr-Ni steel	0.10	18	8	—	Ta + Cb	Provides acid resistance.
Overlay: Copper in strips	—	—	—	—	Cu	For local inductive heating.
Base metal: Mild steel	0.10	—	—	—	—	Provides tensile strength.
Overlay: 18-8 Cr-Ni-Mo steel	0.10	18	9	2.0	Ta + Cb	Provides acid resistance.
Base metal: 20-11 Cr-Ni steel	0.15	20	11	—	—	Provides high temperature strength and scale resistance.
Overlay: 25-4 Cr-Ni steel	0.15	25	4	—	—	Provides scale resistance and sulphur resistance.
Base metal: 25-20 Cr-Ni steel	0.15	25	20	—	—	Provides high temperature strength and scale resistance.
Overlay: Armco iron	0.02	—	—	—	—	Provides stability in salt baths.

Costume Jewelry and Novelty Items Are Centrifugally Cast in Rubber Composition Molds, Vulcanized While Patterns Are in Place. Gates are cut leading from central pouring basin



may be cast simultaneously in one mold, depending upon size, and the entire process can be set up and operated in a space 60 by 60 in.

Casting is done in a centrifugal machine operating at 3600 ft. per min. at the outside circumference of the mold. The molds are merely clamped together and a ladle-full of metal poured into the central cavity, the molds opened and the castings separated from the gates.

Frank K. Smith
Alrose Chemical Co.

Manganese-Silicon Steels for Transmission Gears

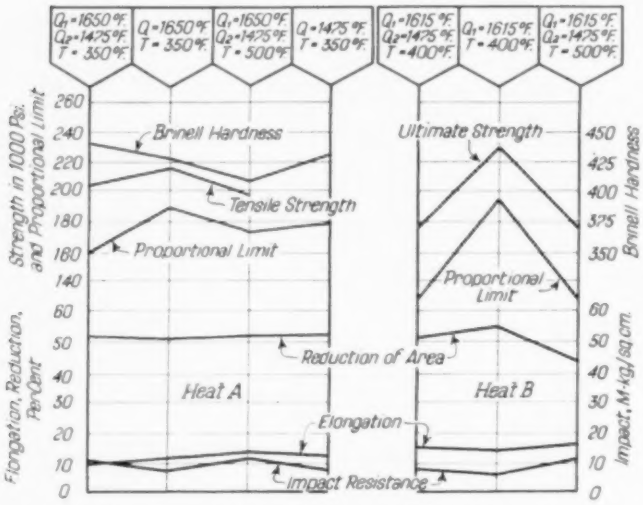
Stalingrad, *U.S.S.R.* — I desire to report the results of a long investigation of new steels for tractor manufacture, designed to utilize the alloying elements readily available in our country. The work was originally based on that reported to the *Transactions* in 1935 by T. N. Armstrong, who, in a comprehensive study of cast alloy steels, found excellent properties in steels comparatively low in alloy content, provided the manganese was above 1%. Interim reports on our studies at Stalingrad Tractor Plant have been published (in Russian) in *Mettalurg* in 1936 and 1937.

The net result is that forged and heat treated low chromium-manganese and chromium-manganese-silicon-copper steels can be substituted even for the higher chromium-nickel steels of the S.A.E. 3300 series for transmission gears and other important machine parts. Forging and rolling is done without difficulty; however the steels containing copper are subject to surface cracking if overheated slightly. Normal quenching, carburizing and other heat treatments proceed normally without tendency to cracking or increased warping.

Five general types of steels were investigated thoroughly and compared with the alloys conventionally used in U.S.A., England and Germany. Typical heats of each type are shown in the adjoining table. All experiments were made on 5-ton heats of basic steel, made in our small openhearth furnace. Types A, B and E are suitable for carburized parts.

Type	C	Cr	Mn	Si	Cu
A	0.24	1.16	1.37	1.16	0.56
B	0.23	0.84	1.02	0.92	..
C	0.38	1.27	1.30	1.36	0.56
D	0.37	..	1.33	1.33	0.48
E	0.21	0.50	0.94	0.33	..

Presence of copper modifies the forging and rolling practice. Forging of Types A, C and D must be started below 2100 to 2150° F. and finished above 1700° F., and done by gradual stages rather than heavy reductions. Heating must be done in a neutral or slightly reducing atmosphere. Failure to observe these precautions will cause a large number of rejects from "fish scale" — a close network of surface cracks



Double Quenching Has no Advantage Over Single Quench for Carburized Steels A and B, Tensile, Impact and Hardness Tests Show

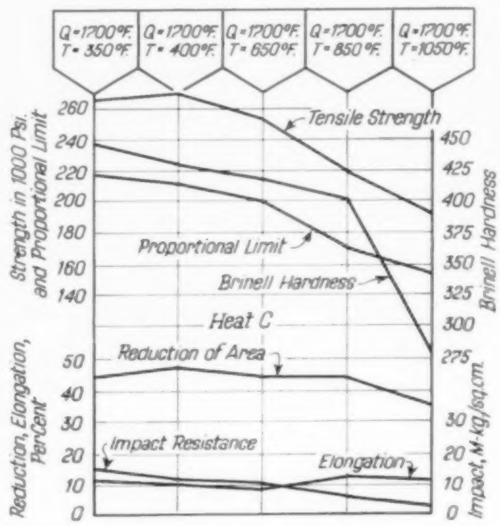
Results of heat treatment of small round or square bars are shown on the accompanying graphs. All samples were quenched from the indicated temperatures in oil and were air cooled after the tempering heats. Tensile test pieces are 10 mm. diameter by 50 mm. gage length (0.394×1.968 in.); Mesnager impact tests were $10 \times 10 \times 55$ mm. in dimension.

The medium carbon Cr-Mn-Si-Cu steel (Type C) is distinguished by high strength and proportional limit; in general its properties are not inferior to the 3½% Ni, 1½% Cr steel, S.A.E. 3335. As quenched and after low tempering its microstructure is fully martensitic of fine needles. Steel D also has high properties, with especially high ductility (reduction of area). Its impact resistance, 5.3 kg-m. per sq.cm., is unexpected for a full-martensitic structure.

in the rolled bars or forged parts. This well-known effect of copper in steel is not associated with undue slag inclusions; all the steels are comparatively clean and the fracture tests showed no internal defects.

Heating and forging of the copper-free steels B and E caused no difficulties. Safe hot working temperature range is 2300 to 1650° F.

Associated with our experiments on best heat treating practice was the determination of the critical range on heating. This was checked both by a dilatometer and by quench-fractures from rising temperatures. Point Ac_3 is between 1510 and 1560° F. for all five steels. The greatest lag on furnace cooling is in Steel A; for this, Ar_1 was noted at 1185° F. It would seem that the various alloy "balances" in our general types do not affect the lower critical temperatures very much; curiously enough the medium carbon steels C and D registered Ac_3 near the *upper* limits of the above-mentioned temperature range.

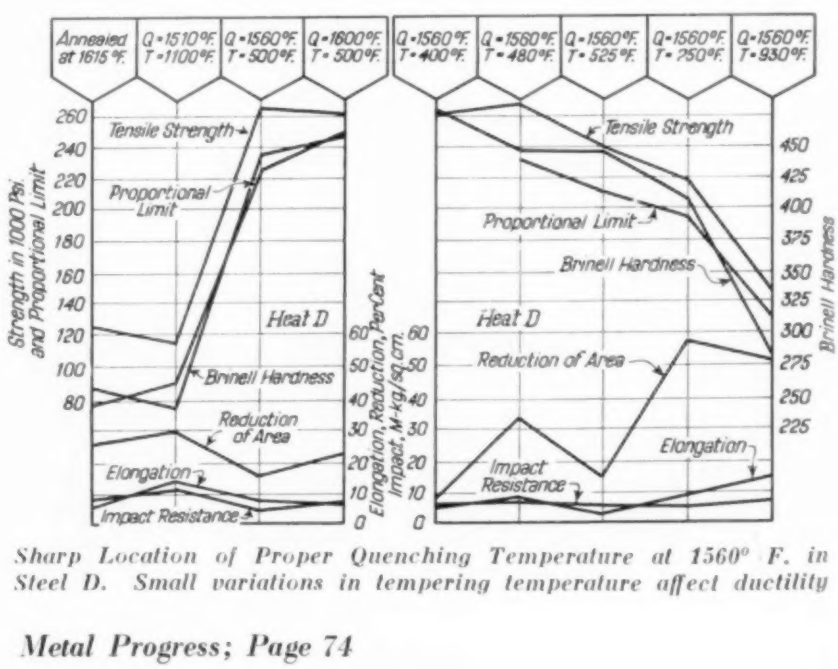


Properties of Heat C, Oil Quenched From 1700° F., Variously Tempered

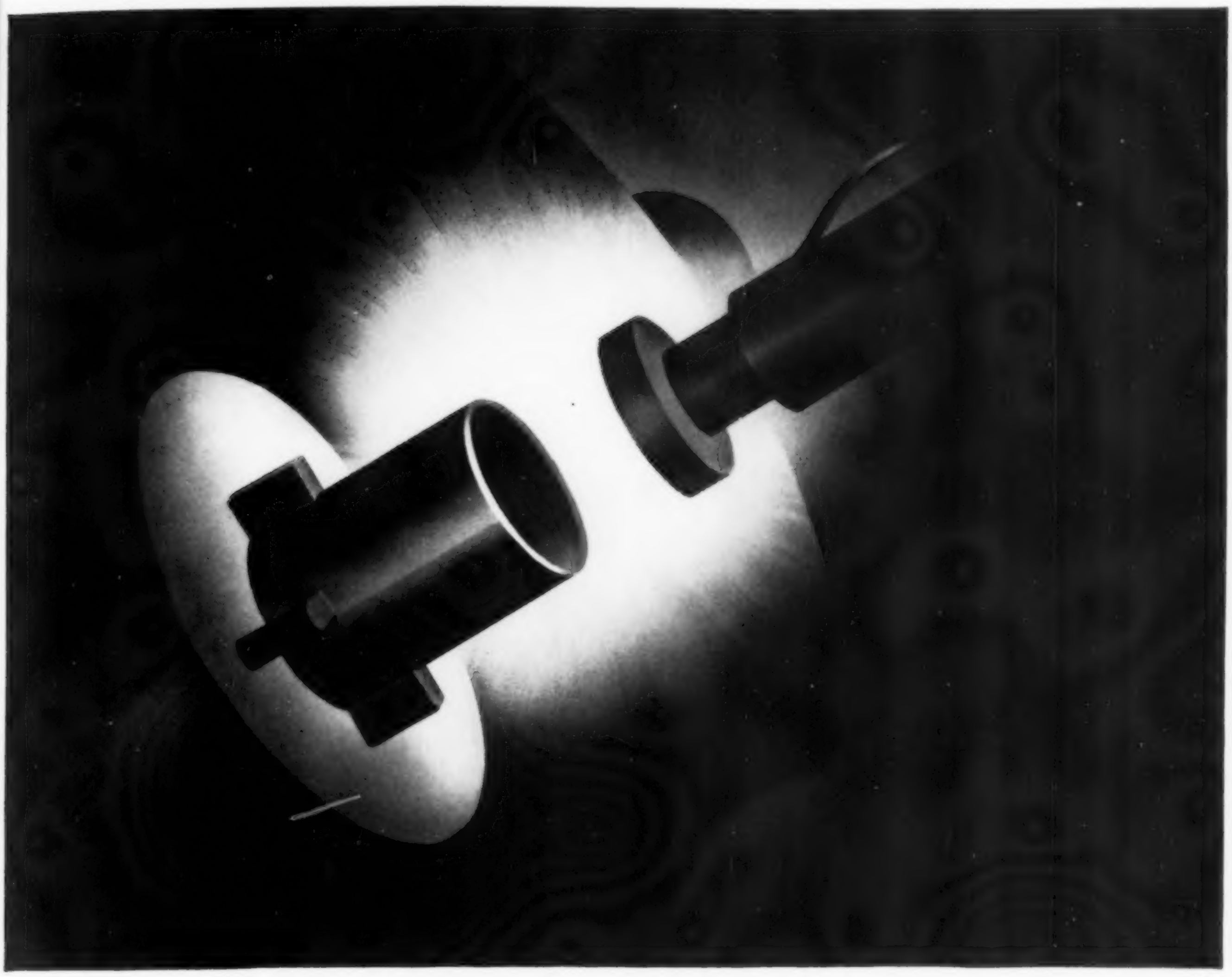
When the properties as affected by tempering temperature are considered, it is apparent that Steel C has the advantage that the curves are smoother. It is therefore less sensitive to small errors in the tempering operation. However, both Types C and D are usable for driving gears on large tractors.

Types A, B and E are usually carburized, so all physical tests were made on bars that had first been soaked at 1700° F. for 10 hr.

(Continued on page 119)



Sharp Location of Proper Quenching Temperature at 1560° F. in Steel D. Small variations in tempering temperature affect ductility



A LITTLE DOES A LOT

Experience in many foundries is proving that good gray iron plus a little Molybdenum will do many an exacting job — and do it economically.

Liners on the steam valve chest of a high pressure pump — a difficult application at best — are a case in point. The manufacturer makes them of good quality gray iron to which is added 1.00% Molybdenum. They are oil quenched and drawn to a hardness of 40-45 Rockwell "C".

He thus meets the difficult requirements for wear resistance at operating temperatures and general reliability, and does it with better than average economy.

A re-study of specifications may indicate similar opportunities in your own production. You will find our book, "Molybdenum in Cast Iron", helpful. It contains complete data on the various Molybdenum irons used in modern foundry practice and is sent free on request.

PRODUCERS OF MOLYBDENUM BRIQUETTES, FERRO-MOLYBDENUM, AND CALCIUM MOLYBDATE

MOLY

Climax Mo-lyb-den-um Company
500 Fifth Avenue · New York City

Personals

Arthur Zavarella has transferred from the chemical and metallurgical laboratory, U. S. Naval Torpedo Station, Newport, R. I., to the chemical and metallurgical laboratory, Springfield Armory, U. S. War Department, Springfield, Mass.

Orville T. Barnett has resigned as metallurgist for Black, Sivalls and Bryson, Inc., of Oklahoma City, to become chief inspector of the electrode department for Metal & Thermit Corp., Jersey City.

C. M. Offenhauer is now employed as a technical assistant for the Union Carbide and Carbon Research Laboratories, Inc., Niagara Falls, N. Y.

Richard K. Lee, formerly research engineer, Timken Steel and Tube Division, is now employed by the McKay Co. of York, Pa., as welding rod engineer.

John Olivieri is employed in the melting department of the Gunite Foundries Corp. at Rockford, Ill.

Gerard H. Boss is working as a metallurgical inspector in the Philadelphia Ordnance District.

Appointed assistant manager, merchants' products dept., American Steel & Wire Co., New York City: **Frank E. Ward**, formerly representing the company on manufacturers' products in the State of Illinois.

Transferred: **George F. Meyer**, from the U. S. Steel Corp. Research Laboratory at Kearny, N. J., to the metallurgical department of American Steel & Wire Co. at Waukegan, Ill., as product metallurgist.

Lloyd B. Kramer, B. S. in metallurgy, Carnegie Institute of Technology, '40, is now employed by the Union Drawn Steel Division of Republic Steep Corp. in the annealing department.

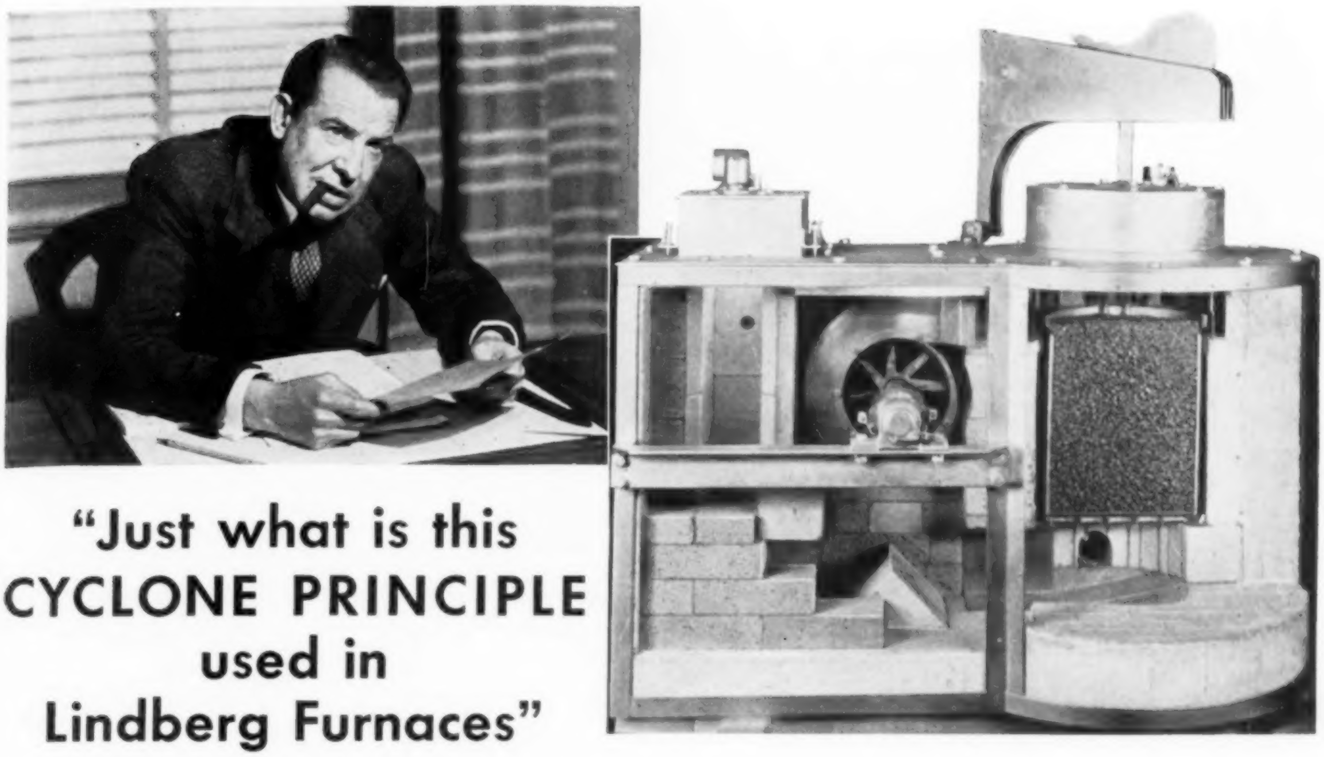
W. J. Ehlers will handle personnel relations for Wright Aeronautical Corp. in Paterson, N. J.

Richard P. Stemmler has been promoted to metallurgical sales engineer for U. S. Steel Export Co.

U. T. Greene, formerly metallurgist, The Standard Tube Co., Detroit, is now assistant metallurgist, Works Laboratory, General Electric Co., Pittsfield, Mass.

Alexander T. Bush is in the sales engineering department of Acme Steel Co., Chicago.

Transferred by Lamson & Sessions Co.: **Alexander M. Smith**, from assistant manager Chicago plant to assistant manager Cleveland plant.



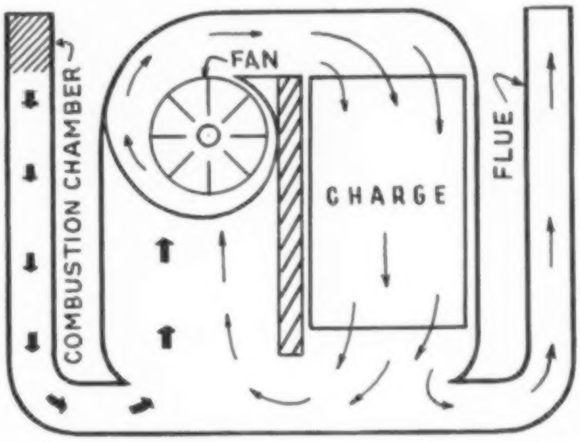
"Just what is this CYCLONE PRINCIPLE used in Lindberg Furnaces"

REMEMBER the old grocery store back in the home town, —how in the winter you used to edge up to that big stove and almost roast your back side while the rest of you darn near froze? Now contrast this with the theater you went to last night. You felt warm all over,—yet there was no heat actually created in the room. It was probably generated in a heating plant way down below the stage and blown up and out into the auditorium through numerous vents.

Now let's substitute a Cyclone tempering furnace for the theater. For the audience we'll substitute a charge of 3/8 inch number six self tapping screws. If we place this charge of screws in the Cyclone furnace where the heat is accurately generated in a separate chamber *away* from the charge, and then driven under high pressure and at a two mile a minute velocity into every part of the chamber carrying these screws, we can be sure that all will be quickly heated to exactly the same temperature.

Just as the modern heating plant in the theater kept you warm not just on one side, but all over, so the unique Cyclone forced convection heating principle brings all parts of the charge to uniform temperature, turning out work within most exacting hardness tolerances. This speeds production by eliminating rejections and the necessity of retempering due to poor hardness uniformity. Startling cost reductions often exceeding 50% result from savings effected by reduced fuel consumption, not to mention additional economies resulting from the saving of time formerly spent in washing oil quenched work, and the absence of frequent maintenance or repair shut downs. In these times of far-above-capacity-production these points are really important to you. Many Cyclones have been known to show a complete return on the investment within 6 or 7 months.

Special bulletins giving a more detailed explanation of the Cyclone principle are available on request. Lindberg Engineering Company, 222 North Laflin Street, Chicago.



LOOK TO LINDBERG FOR ACCURACY

LINDBERG FURNACES

CYCLONE FOR TEMPERING • HYDRYZING FOR HARDENING

Personals

W. J. Jeffries has been appointed chief inspector, Philadelphia Ordnance District, U.S.A.

Michael Bock, II, formerly with Republic Steel Corp. in Buffalo, is now junior metallurgist, U. S. Navy Yard, Boston.

Transferred by General Electric Co.: **Walter L. Fleischmann**, from industrial control engineering department to the works laboratory, where he will be engaged in electrical and mechanical development work.

Ralph M. Gelburd, formerly with Bethlehem Steel Co., is now a chemical supervisor, research and development, Merck & Co., Rahway, N. J.

E. H. Mebs has resigned as metallurgist of the Ohio Steel Foundry Co., Lima, Ohio, to accept a position with the United States Steel Corp.

Harold M. Malm has left the Lee Spring Co. to join Callite Tungsten Corp., Union City, N. J., in connection with the alloy wire division.

James E. Wilson has resigned as metallurgist of the Bausch & Lomb Optical Co., Rochester, to become associated with Brace-Mueller-Huntley, Inc., in Buffalo.

H. A. Scallen, formerly representative in the New England territory for the Jessop Steel Co., has been appointed district manager for the Hartford branch. **H. F. Robertson** has been appointed sales representative with offices in Hartford.

F. G. Jenkins, 1st lieutenant, Ordnance Department, formerly with Eastman Kodak Co., has been ordered to active duty at Watertown Arsenal, and has been assigned as chief of the Procurement Section.

Lt. F. X. Bradley, Jr. is now involved in the organization and operation of the Air Corps Advanced Flying School at the newly organized Southeast Training Center in Montgomery, Ala.

A. Justus Larson, formerly metallurgist's assistant at Carnegie-Illinois Steel Corp. Homestead Works, is now affiliated with the Eastman Kodak Co., Rochester, N. Y.

William Pennington has left the American Rolling Mill Co. to take a position as industrial fellow at Mellon Institute of Industrial Research in Pittsburgh.

Robert William Kinnear is employed by the Allison Engineering Division of General Motors Corp. in Indianapolis as apprentice inspector on rough castings.

Personals

Walter H. Lewis ⊕ has received a leave of absence from Jones & Laughlin Steel Co. to go on active duty with the Navy.

Elected president of the American Standards Association: **R. E. Zimmerman** ⊕, vice-president, United States Steel Corp.

Awarded the Holley Medal of the American Society of Mechanical Engineers: **Charles F. Kettering**, chief of research of General Motors Corp., honorary member ⊕.

Roy D. Johnson ⊕ is now technical trainee with General Mills, Inc., Minneapolis.

I. C. Sleight ⊕ is a junior metallurgist with Wright Aeronautical Corp., Paterson, N. J.

Harrison I. Dixon ⊕, formerly metallurgical sales engineer for Electro-Alloys Co., Cleveland, has been appointed assistant general manager of Park Chemical Co., Detroit.

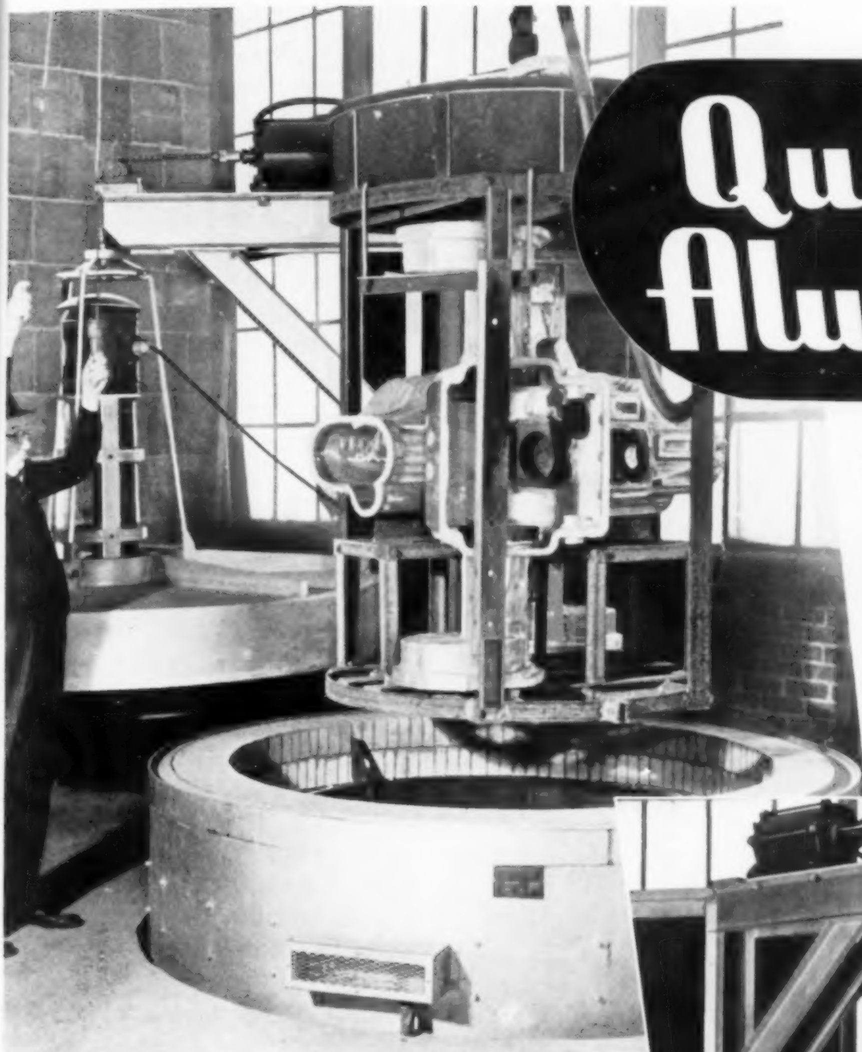
Promotions by Carnegie-Illinois Steel Corp.: **E. E. Moore** ⊕, to vice-president, industrial relations; **S. M. Jenks** ⊕, to succeed Mr. Moore as general superintendent of Gary Works; **E. G. Hill** ⊕, to succeed Mr Jenks as assistant general superintendent; **Arthur D. Beers** ⊕, formerly chief metallurgist, to succeed Mr. Hill as assistant to general superintendent. At South Works: **Harry A. Strain** ⊕, promoted to director of raw materials, fuel and power; **M. J. Devaney** ⊕, to succeed Mr. Strain as assistant general superintendent; **Michael F. Yarotsky**, to succeed Mr. Devaney as division superintendent of steel production; **George E. Gustafson** ⊕, to succeed Mr. Yarotsky as assistant superintendent of steel production; **Howard A. Parker** ⊕, to succeed Mr. Gustafson as superintendent of No. 2 openhearth; **George W. Bruce** ⊕, to succeed Mr. Parker as assistant superintendent of No. 2 openhearth.

E. Robert Eaton ⊕ is now working in the metallurgical department of Bethlehem Steel Co's Maryland plant.

George McP. Glenn ⊕, formerly with Jones & Laughlin Steel Corp., Pittsburgh, is now with Republic Steel Corp., Canton, O.

D. F. Rundle ⊕ is on a one year's leave of absence from Centrifugal Fusing Co., Lansing, Mich., where he was metallurgist, to be on active duty with the 61st Coast Artillery at Ft. Sheridan, Ill.

Forrest S. Williams ⊕, formerly a metallurgical technical apprentice at the American Steel & Wire Co., Waukegan, Ill., has accepted a civil service appointment as junior metallurgist at the Naval Aircraft Factory in Philadelphia.



Quality Aluminum

and HEVI DUTY FURNACES

An HD 6084 Pit Type Furnace at the Quality Aluminum Casting Company, Waukesha, Wisconsin

To insure accuracy in their heat treatment of aluminum alloy castings and to develope the maximum physical properties of the metal thru a controlled heat treating cycle, the QUALITY ALUMINUM CASTING CO. of Waukesha use a Hevi Duty Pit Type Furnace.

Send for Hevi Duty Furnace Bulletins

HEVI DUTY ELECTRIC COMPANY

HEAT TREATING FURNACES HEVI DUTY ELECTRIC EXCLUSIVELY

MILWAUKEE, WISCONSIN

Wear Resistant Cylinder Liners

By J. E. Jackson

Abstract from "Wear Resistant Coatings of Diesel Cylinder Liners" in S.A.E. Journal *(Transactions) January 1941, p. 28*

Careful "run-in" of a diesel engine (or other precision machine) is a time when the machine is brought from idling up to full speed and load according to definite schedule. Its prime objects are two: *(a)* To enable skilled attendants to adjust occasional abnormalities and assure a more nearly uniform product, and *(b)* to "mate" all bearings. The term "mating", in this sense, does not refer to any improvement or change in the dimensional fit between bearings, but does refer to an improvement in the compatibility between the contact surfaces of all bearing couples.

An important "bearing couple" is the assembly of piston, piston rings and cylinder liner. Rapid mating of these moving surfaces is necessary to establish almost immediately and to preserve the initial working compression ratio of the engine. Any blow-by of hot gases will blast away the oil film, cause the lubricating oil to change its nature, and erode the metal surfaces. In many respects the early stages of run-in are most critical on the cylinder liner, at the very time when it is most difficult to maintain an effective film of oil.

In the original S.A.E. publication the surfaces of cylinder liners are illustrated at various magnifications and after various treatments. For instance, a liner, finish honed, has helical scratches clearly apparent even though they are 1½ to 3 micro-inches deep. After a 10-hr. run-in these micro-scratches were partly obliterated and replaced by another and even deeper set, straight and parallel to the axis. The remaining honing marks would have been obliterated in the next 4 or 5 hr. of full-load running.

The scratches that are prominently noticeable upon the liner bore surface after honing and after run-in are directly associable with deformation of the surface metal beyond the yield point. Such deformation adjacent to each scratch fulfills the basic requirements of work hardening. Since honing subjects the surface to deformation

through metal removal as well as through flow by scratching, it is conclusive that the honed bore is coated with a thin layer of work-hardened or strain-hardened metal in random distribution. Many of the wear resisting properties of the bore surface are derived from a coating of strain-hardened metal upon it; it is the formation of such metal coating, properly oriented in the direction of reciprocation, that constitutes the "surface conditioning".

It was remarked above that the early stages of run-in are critical. In the beginning, the surface of the liner is notoriously difficult to lubricate, for not only is the dynamic surface energy lowered by adsorbed gases and machine oils but also there are few regions on the surface to serve as capillaries. The honing scratches are very shallow in proportion to their width; therefore, they offer little aid in the retention or spreading of lubricating oil. The ability of the graphitic carbon of the cast iron to aid in either holding or spreading lubricating oil over the new liner bore surface has been, in the writer's opinion, over-estimated; this property of the graphite is not fully developed until after it has been fully exposed by the removal of the metal flowed over the flakes by honing and by running-in.

When any amount of metal at the surface is deformed into a new orientation, work must have been done upon the metal so deformed. When the amount of this work is large with respect to the deformed mass, and when the work is done at a rapid rate, the metal involved will rapidly rise in temperature. Unless the two bearing surfaces are sufficiently isolated by the lubricant, welding will occur. At any time the conduct of the run-in must be so gradual that seizure or welding will never become of such magnitude to cause "scratching" or "scuffing".

Many of the problems associated with the running-in of honed cylinder liners have been alleviated by giving the liners chemical treatment as a final operation prior to engine assembly. The liners, after finish-honing, are cleaned and then immersed in a concentrated water solution of sodium hydroxide and a small amount of sulphur. The process is one of etching and, literally, might be called "a controlled pitting process". Any free ferrite at the bore surface (and free ferrite should not be in any bore surface) is etched from the matrix. The carbide constituent of a pearlitic

(Continued on page 106)

Cylinder Liners

(Continued from page 91)
matrix is also reacted upon by the solution and the ferrite in the fine lamellar pearlite is etched away leaving pits filled with etching end-products.

After such treatment (known as the "Surfide Process" and developed by Standard Oil Co. of Calif.) the surface becomes deep gray, almost black in color. Its surface roughness is largely increased from the 1½ to 3½ micro-inches of the honed surface to 9 to 11 micro-inches. After run-in this is reduced slightly to 7 to 9½ micro-inches, and the bore surface has not recovered the bright shiny appearance which it showed before chemical treatment. Dull appearance is attributed to the residual pits in the surface, too deep to be removed during the run-in.

It is believed that this chemical treatment makes the liner bore surface more susceptible to safe run-in by removal of the undesirable components of surface composition; by deposition of certain chemical end-products on the surface; and by change in the surface configuration.

The important surface metal to be removed by the etching is the strain-hardened metal formed on the surface by honing, so that the metal exposed is comparatively soft and more susceptible to plastic movements during run-in.

It is held that the most readily welded constituent of the cast iron of either piston rings or liner is free ferrite, and the removal, by etching, of exposed ferrite in either piston ring or cylinder adds to the facility of the run-in. Corrosion also removes certain loosely held particles at the very surface which otherwise would drop out and promote scuffing and scratching.

The coating deposited on the liner bore by etching in the caustic sulphur solution serves in several capacities. Its composition is ferrous oxide and ferrous sulphide; not only does its matte surface facilitate rapid spread of lubricating oil, but also oil is retained in the porous inner structure of the coating.

When the temperature of a small surface area is caused to increase rapidly through deformation, sulphur, from decomposed ferrous sulphide, will help prevent welding.

The microscopic pits formed by etching, with their porous sulphide-oxide contents, serve as reservoirs to hold a supply of lubricating oil for local surface needs.

3.7-In. Shell

(Continued from page 53)

guide the stationary piercing punch, which is threaded and seated in the cylinder head. Thus, the billet is accurately located in the die pot by its beveled edges, and the piercing punch is guided by the locating pad which has entered the die pot. Through this arrangement, the hole must come central in the forging.

Maintenance of piercing punches is a problem. The punch is in contact with hot metal about 4 sec., and on withdrawal is sprayed and cooled. Number of operations per hour is reduced to half the theoretical speed of the machine in order to prevent overheating the punches, yet even so the temper is drawn in about an hour (100 operations). The punch can be redressed and retreated two or three times. Best material so far found is a hot die steel containing 0.30% carbon, 11% tungsten, 3.25% chromium and 0.40% vanadium, heat treated as follows: Anneal at 1550° F., slow cool in furnace, preheat 2 hr. at 1200° F., then up to 1500° F. for 15 min., cool in still air, double draw 2 hr. each in salt baths at 1325 and at 1175° F. to Rockwell C-30 to 32.

The "bottle" from the piercing press is put into a holding furnace to equalize temperature and then placed in a V-block in front of the roll housings. A mandrel about 0.03 in. smaller than the piercing punch is thrust forward by a hydraulic cylinder and, bottoming in the shell cavity, pushes the hot steel bottle through a series of five closely set roll housings that reduce its outer diameter from about 5 in. to about 4 in., and increase its length to about 15 in. Each of these housings contains three rolls set with axes at 120° and so shaped that the round central passage is completely enclosed. On the ram's return stroke, the forging is engaged by a set of fingers set just beyond the last roll and the ram pulls free. Hot forgings are closely stacked on end in a sand bed, so they normalize by slow cooling.

The ram or mandrel is made of the same material as the piercing punch, and is water cooled after each operation and then swabbed with a mixture of 1 part graphite and 5 parts quenching oil. It has a life of 1500 operations before redressing is required. Rollers are made of heat treated steel analyzing 0.55% carbon, 0.75% chromium, 1.60% nickel and 0.75% molybdenum. After 25,000 operations the rolls are turned down to the next size; this life is far greater than that of draw rings.

Forging stainless

(Continued from page 59)

treated or annealed. Steam valve seats are usually quenched from 1750° F. into oil, and drawn at approximately 900° to hardness of about 321 Brinell. At this hardness they will resist wear and "wire cutting" by steam. Valve stems from the free machining grade are treated to hardness values of approximately 241 Brinell, and are easily machinable at this hardness. The presence of sulphur in the alloy helps to avoid galling on rubbing surfaces or seats.

Cutlery items are quenched from temperatures around 1800° F. or higher. Such high temperatures are necessary to get the best corrosion resistance. The higher carbon alloys for cutlery are quenched from 1850 to 1900° F. to get maximum hardness; the high temperature is required to get the chromium carbides in solution. Tempering may be around 400 to 500° F. and the hardness will then be higher than 500 Brinell.

Any items of this group can be annealed by slow cooling from 1550° F. The low carbon, 16% chromium alloy of Group No. 2 is always annealed at about 1500° F.

Alloys of Groups 3 and 4 are practically always annealed after hot work. The temperatures will be in excess of 1800° F., and heating is followed by quenching in water to retain the austenitic condition (all carbides in solution). The forgings will be comparatively soft, their hardness measuring under 175 Brinell.

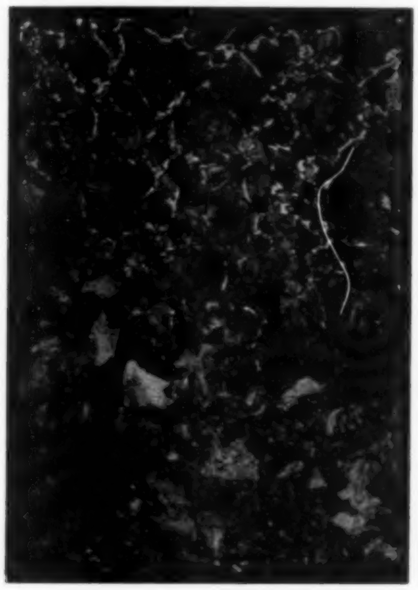
Finishing

All forgings require some method of cleaning. Usually they can be sand blasted, tumbled, and then pickled in proper acid solutions. Sulphuric and hydrochloric will be suitable for items made of the martensitic or ferritic alloys. Nitric acid containing hydrofluoric or hydrochloric acid is necessary to take the scale off the austenitic alloys; this is followed by a dip in HNO_3 for "passivation". Generally such parts are machined or may be ground and polished, depending upon the application. Valve seats are machined. Cutlery and golf club heads are ground and polished. Balls, bearing races, valve stems and valves are given a high finish by grinding and even lapping.

Mn-Si Steels

(Cont. from p. 74) The curves on page 74 show tensile, impact and hardness tests after double and single quench from temperatures suitable for case and core. No advantage accrued from double heat treat as compared with single.

Carburizing tests were made, 6, 10 and 14 hr. at 1715° F. in a mixture of 10 parts charcoal and 1 part sodium carbonate. The accompanying micro at 100 diameters shows a typical carburized structure; this particular one is Steel A



Microstructure (100×) of Carburized Case on Cr-Mn-Si-Cu Steel A After 14 Hr. at 1715° F.

(with copper) after 14 hr. General conclusions to be drawn are:

I. Fourteen-hour carburizing is best, giving a hyper-eutectoid zone 0.015 in. thick and an eutectic (fully pearlitic) transitional zone 0.050 in. thick.

II. Type A carburizes somewhat slower than Steels B and E.

III. Type A has the smallest grain size.

IV. Type B has the most uniform eutectoid zone.

Transmission gears made from Steel A, carburized, and oil quenched gears from Types C and D, were run in competition with gears of similar treatment made of appropriate chromium-nickel steels, and gave equally good results in the way of wear resistance.

M. P. Brown
Chief of Metallurgical Laboratory
Stalingrad Tractor Works